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DEVOTED TO

SCIENCE AND THE MECHANIC ARTS.

EDITED BY

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RECENT PROGRESS IN CHEMICAL TECHNOLOGY.

BY SAMUEL P. SADTLER, PH.D.,
Professor of Chemistry in the Institute.

[*An introductory lecture to the Chemical Course at the Franklin Institute, 1893-94.*]

It having fallen to my lot as Professor of Chemistry in this time-honored Institute to open the course of chemical lectures for the season of 1893–94 the question presents itself at the outset as to how the subject should be taken up. This question is not difficult of solution if we first determine what bearing the science of chemistry has upon the fundamental aims and purposes of the Institute. We have clearly stated in the official title of the Institute the fact that it is constituted for the "Promotion of the Mechanic Arts." Obviously then it is essentially chemistry as applied in the arts that we should concern ourselves with. A thorough grounding in the principles and theories of the science

as preparatory to this study of its applications might be included in this field to be occupied by the Institute if her means and facilities allowed of it. But for the present, and until the Institute can boast of those newer quarters and larger resources that her friends have been hoping for, she will have to content herself with endeavoring to fill in a narrower sense the object of her organization.

Looking at the specific relations of chemistry to the mechanic arts, therefore, it has seemed to me desirable to open the series of chemical lectures with a "Review of Recent Progress in Chemical Technology."

In the production of the metals, the most notable advances made in recent years are those which concern the light metals, aluminum, magnesium and sodium, and these advances have been largely coincident and connected with the great improvements in applications of electricity. Thus, until the issue of the Grætzel patents in 1883, aluminum was manufactured solely by the Deville process, at Salindres, France, and later at Oldbury, near Birmingham, England, under Webster's patents. In 1885, the Cowles electric process was made public and has continued in use to the present time. Heroult's process, also an electrical one, was patented in 1887, and is at present being worked on a large scale, both in Switzerland and France. Hall's process, patented in 1889, and Minet's, which is practically identical with Hall's, however, represent the most successful applications of the electrolytic method to the production of the metal aluminum. So it has come about that the Aluminum Company, of Oldbury, England, although it has cheapened the price of sodium under Castner's patents and controls Webster's improvements on Deville's process is unable to make aluminum in competition with the electrolytic methods and has retired from that field. In this country and in England, the two processes now in use are those of Hall and Cowles, while on the Continent, the Heroult and the Minet processes are followed.

The production of aluminum in 1892 was as follows: In the United States, 133,779 kilos; by the Aluminium Industrie Actien-Gesellschaft, at Neuhausen, in Switzerland, 286,100

kilos; and by the Société Electro-Metallurgique Française, Isère, France, 60,000 kilos. The English production I have not seen stated.

At the Columbian Exposition the raw materials and the products of the aluminum industry were very satisfactorily shown by the Pittsburgh Reduction Company, and some individual exhibitors in the galleries of the Mining Building. The beauxite used as the source of the alumina is now mainly supplied from the Alabama and Georgia deposits, which were also well illustrated in this connection.

As the Aluminum Company, of Oldbury, England, as just stated, have had to retire from the competition with the electrolytic processes, they have devoted themselves to the production of sodium and, in looking for new utilizations for the metal, have brought out sodium peroxide as a commercial product. This has already found a large sale for wool and silk-bleaching and other purposes for which hydrogen peroxide has been used. As compared with barium peroxide and hydrogen peroxide (10 volume solution) it contains available oxygen as follows:

	Available Oxygen. Per Cent.
93 per cent. sodium peroxide	19.5
91 per cent. barium peroxide	8.6
10 volume solution hydrogen peroxide	1.6

It is made, according to Castner's patent, by treating metallic sodium contained in aluminum vessels at a temperature of 300° C. to the gradual oxidizing action of a mixture of oxygen and nitrogen in which the proportion of oxygen is gradually increased. This is done in an iron pipe which passes through the furnace and along which a current of air is passed from one end. The vessels containing the sodium pass along the entire length of the pipe, the sodium being oxidized at first by air which has almost been deprived of its oxygen, the proportion of the latter gradually increasing until it is finally oxidized by air containing the full amount of oxygen. The product is a yellowish white partially powdered substance, which dissolves in water with considerable evolution of heat. It may be used to develop hydrogen peroxide just as the barium peroxide

is used, or used direct with the addition of a magnesium salt in order to convert it into the magnesium peroxide, the alkalinity of the sodium peroxide when taken alone being injurious.

In turning to the metallurgy of the heavier metals, there are improvements capable of being discussed in the case of many of them, but for the purposes of this review we will have to choose only the most prominent for mention. The one which has certainly attracted the most attention on the part of chemists is the so-called "cyanide process" for the extraction of gold and silver from their ores. While the fact of the solubility of gold and silver in cyanide of potassium solution has been known for years and applied in electro-metallurgical processes, the application of this solvent power of the cyanide for the extraction of the finely disseminated metal from the ore has only been made in the last few years. The process has been applied in the United States under the patents of Simpson and others and on a larger scale in the South African gold fields under the patents of MacArthur and Forrest. The process as applied to gold ores is in outline as follows: The damp tailings are charged into wooden vats of a capacity of fifty to seventy-five tons and the vats filled to within a few inches of the top. Cyanide solution of 0·6 to 0·8 per cent. strength is then allowed to flow into the tank until it is completely filled. This solution is allowed to remain undisturbed in contact with the ore for twelve hours. Each vat is provided with a false bottom covered with some straining material, usually cocoanut matting. Below this is a layer of coarse sand and pebbles, through which the solution percolates. An iron pipe communicating with the vat below the false bottom takes the filtered solution to the "zinc boxes," when precipitation takes place. As the liquor is drawn off during the leaching process, it is replaced by fresh solution. This operation is continued from six to twelve hours, according to the value of the tailings. At the end of this period, which is known as the "strong solution leaching," a weaker solution (containing 0·2 to 0·4 per cent. of cyanide) is turned on and allowed

to filter through the ore for about eight to ten hours. When this is drawn off a quantity of wash-water about equivalent to the moisture originally contained by the ore is run in and the weak cyanide solution so displaced. The amount of cyanide solution used is about half a ton of strong and half a ton of weak solution for every ton of ore treated. This part of the process has been modified by pumping back the solution as it filtered through the bottom of the vat and so keeping up a circulation of the original solution for some thirty-six hours. The extraction of gold by this circulation system was equal to that obtained by the ordinary method and the consumption of cyanide was much less. The cyanide solution carrying the gold dissolved now goes through wooden troughs, commonly known as "zinc boxes," where shavings of zinc cause the deposition of the gold as a finely divided black slime upon their surface. After passing the "zinc box," the "exhausted solution," which should not retain more than a trace of gold, flows into a storage tank to be pumped back to the leaching tanks when a fresh charge has to be treated. Very great loss of cyanide takes place by secondary decomposition of the potassium salt, due to the galvanic action of the gold-zinc couple that is formed. The slime of finely divided gold and silver with a large proportion of zinc and lead and smaller amounts of tin, antimony and accidental impurities after thorough settling and transferred to enamelled iron pans and carefully dried. It is then mixed with sand, borax, and bicarbonate of soda and melted in a crucible yielding a bullion about 650 fine.

In the Molloy process, which is said to be in successful operation in South Africa, the use of zinc is dispensed with altogether. The cyanide solution from the leaching tanks passes through a shallow trough containing mercury, in which is an inner cylindrical vessel filled with solution of carbonate of soda; the edges of the cylinder just dip beneath the mercury so that its contents are entirely cut off from the outer portion of the vessel. A rod of lead dips into the soda solution; the lead and mercury are connected with opposite poles of a battery, and the solution is electro-

lyzed by the passage of a current. The sodium combines with the mercury to form sodium amalgam which at once decomposes the gold cyanide solution with formation of ordinary gold amalgam, sodium cyanide being simultaneously produced. It is claimed that much less decomposition of the cyanide takes place than with zinc, and moreover that the outflowing solution is better adapted for dissolving fresh quantities of gold. In the ordinary method a large accumulation of zinc in the solution must take place, which in time renders them valueless for gold extraction whereas sodium cyanide is just as effective as the potassium compound.

Turning now to the acid and alkali industries not much of fundamental importance is to be noted in the former. At the Columbian Exposition were shown in the exhibit of Heræus, of Hanau in Germany, large platinum stills of the Faure and Kessler system, in which the interior of the still was plated throughout with gold. It has been found that this surface of gold will stand the action of concentrated sulphuric acid much longer than one of platinum. I have since seen two such stills in operation in a large chemical works and understand that the claim is thoroughly borne out in practice.

Perhaps the most important matter of interest in connection with the alkali industry, is the attempt now being made by numerous experimenters to accomplish a commercially successful electrolysis of salt solution with chlorine and caustic soda as the products. The results, with two of the most prominent processes (the Greenwood and the Le Sueur) were summed up some months ago by Messrs. Cross and Bevan, of London, England, and from their article (*Jour. Soc. Chem. Ind.*, 1892, p. 963) we shall quote. The chief difficulties met with were the devising of a diaphragm of such low resistance as would allow the electrolysis to proceed with a reasonable low electro-motive force, and which would at the same time effectually prevent the recombination of the products of electrolyzer; and the construction of an anode which would stand wear and tear. In the Greenwood process, "the electrolysis consists of a rectangular

tank of slate or other suitable material divided into compartments by means of diaphragms. These are made of a number of V-shaped shelves of glass or slate placed in a mahogany frame. The spaces between the shelves are filled with asbestos. On one side of the diaphragm is the cathode made of iron and on the other side is the anode. This is of peculiar construction, being built up of a number of pieces, of hard retort carbon cemented together by first impregnating with tar and subsequently heating to a high temperature. The inside is filled with type metal. The cathodes and anodes in every electrolyzer are connected together in parallel circuit, the electrolyzers themselves being in series. Arrangements are made by means of pipes for allowing the salt solution, which is about half-saturated, to flow through all the anode and cathode sections, respectively. The chlorine which is evolved passes into the chlorine main. The caustic solution after passing through a sufficient number of electrolyzers is evaporated, and the excess of undecomposed salt removed." In the Le Sueur process, the electrolyzers consist of an iron tank fitted with a sloping floor on which rests the cathode. This is formed of a ring of iron filled with several pieces of iron wire gauze. Several small holes are drilled in the top part of the ring to allow of the easy escape of the hydrogen. The diaphragm, which rests upon the cathode, consists of two parts, a sheet of ordinary parchment paper, and a double sheet of asbestos cemented together by means of coagulated blood albumen. The anode consists of pieces of ordinary retort carbon imbedded in a mass of lead through which electrical contact is obtained. In this process the diaphragms have to be renewed every forty-eight hours, and the carbon anodes in from six to eight weeks. When the electrolysis has been continued long enough for the solution of caustic to reach a strength of about ten per cent. the liquor is run away, and the alkali precipitated as bicarbonate. The Le Sueur process is now in operation at Rumford Falls, Me., on a scale of three tons of bleach per day. E. Hermite and A. Dubosc (*Zeitsch. für Angew. Chem.*, 1892, p. 729) claim that all these attempts at simple electrolysis of salt solutions will

remain unsatisfactory, because the heat of the combination of sodium and oxygen is less than that of sodium and chlorine, so that a current of sufficient electro-motive force to decompose sodium chloride will also decompose the sodium oxide as fast as formed. Thus the electro-motive force used is practically wasted. They have proposed and patented two methods for preventing this. The first is to cause the sodium oxide in the moment of its formation to enter into combination to form a sodium salt possessing a higher heat of chemical union than sodium chloride, so that the electro-motive force of the current may remain constant. Such a compound they find in sodium aluminate, which will form if pure gelatinous alumina be present in the salt solution undergoing electrolysis. As soon as all the alkaline chloride is decomposed, the current is stopped, and carbon dioxide is led into the solution when the alumina hydrate is again set free while sodium carbonate is formed. Their other proposal is to use as cathode plates of amalgamated copper or other metal over which a thin layer of mercury is continuously made to pass. As the alkali metal separates out, it is amalgamated, and this sodium amalgam is, by a special device, removed promptly into another receptacle where it is decomposed by water, with the formation of caustic soda solution.

I am not aware that these proposed processes are as yet carried out on a practical scale. Cross and Bevan, however, state that the original Hermite process for the continued electrolysis of magnesium chloride solutions for bleaching purposes is proving highly successful on the continent of Europe, and that it is now replacing 3,000 tons of bleaching powder per annum.

While the two great products sought to be obtained in all of these processes above described are chlorine and caustic soda, it must not be overlooked that these are side products. In the solution will be found hypochlorites and chlorates also. In connection with the Greenwood process it has been proposed to extract the latter salt.

An entirely different utilization has, however, been proposed for weak electrolyzed brine solutions, depending upon

the development of hypochlorites therein. I refer to their use as disinfecting agents. The Woolf process, as taken up for experiment by the New York City Board of Health, proposes to disinfect large quantities of liquid sewage by adding to it weak electrolyzed brine solutions, and it is stated by Dr. Cyrus S. Edson to have accomplished very remarkable results in the experiments made under his direction in New York.

In the class of nitrated mixtures for explosive purposes there has been much published and patented in the last few years. The improvements have been mainly in two lines, viz: smokeless powders and high explosives which combine safety of transport and handling with great energy of decomposition. The former are largely mixtures of nitro-cellulose and nitro-lignin (both soluble and insoluble varieties) with alkaline or alkaline-earth nitrates. A very interesting series of analyses of such smokeless powders, by Prof. C. E. Munroe, formerly of the United States Naval Torpedo Station, at Newport, will be found in the January number of the *Journal of the American Chemical Society.* The second class include mainly mixtures of substances very rich in oxygen, whether solid or liquid, and highly condensed carbon compounds. To these belong the series of Sprengel explosives, rack-a-rock (chlorate of potash and nitro-benzene) and similar compounds. These can be mixed frequently on the spot just before use, and so safety of transport insured as the compounds taken singly are inexplosive or in some cases peculiar detonating fuses are needed to develop their explosive power.

Very great interest has attached in recent years to the discovery of large and valuable deposits of native phosphates of value in the manufacture of fertilizers, but as a special lecture on this subject by a gentleman who has had exceptional opportunities of studying these deposits, will follow later in the course, I will leave the matter, feeling that it will be thoroughly discussed at that time. Similarly the cement industry and especially the manufacture of Portland cement, which has made great advances in the United States in the last few years, will be left for a special lecturer

to follow later in the winter, a gentleman engaged himself in the manufacture of cement, and by the newest and most improved methods. A lecture is also down on our list on the subject of "Emery and other Abrasives." In this will doubtless be mentioned the very interesting new compound; known by the trade name of "carborundum." By heating together a mixture of 100 parts of sand, twenty-five parts of salt and twenty-five parts coke in an electrical furnace for several hours is formed along with graphite a new and interesting chemical compound SiC (silicon carbide), to which the trade name of "carborundum" has been given. This forms crystals of a greenish-gray color of the hexagonal system, of specific gravity 3·22, and of a hardness little if any inferior to the diamond. A full account of the discovery and properties of this interesting compound by the discoverer, Mr. Ed. G. Acheson, will be found in the September and October numbers of the *Journal of the Franklin Institute.*

Turning now to the organic side of Chemical Technology, and beginning with the subject of petroleum and mineral oils, we may notice the interesting results of Professor Engler, of Carlsruhe, of which he presented a brief abstract in a paper read before the Chemical Congress at Chicago, in August last. He finds that almost all the animal fats and fatty oils when distilled under strong pressure yield hydrocarbons of the paraffin series. Besides the oil some water and combustible gas was always formed. By fractional distillation the oils yielded gasoline, benzine, illuminating and lubricating oils and even paraffine wax. Samples of all these prepared from train oil were shown in connection with the reading of his paper. The bearing of all this on our theories of the formation of petroleum is very important. Many prominent geologists have expressed the view that the origin of petroleum was to be sought in marine animal life, of which we find the mineral remains in the oil-bearing strata. Engler first distilled quantities of salt-water fishes and shells under strong pressure, but only obtained a mixture of nitrogenous bases, such as pyridine, bearing no relation to petroleum. But, as before said, the results were very different with train and fish oils. He therefore

believes that while the easily decomposable nitrogenous material of marine animal life has disappeared, the accumulated fatty oils and blubber under the pressure of sedimentary strata, and aided perhaps by heat, have undergone destructive distillation with petroleum as the main products.

A new class of products of considerable practical interest derived from the class of semi-drying oils, like cotton-seed and rape-seed oils, is that known as "blown oils." These are produced by heating the oils to a temperature of about 200° C. for some hours while a current of air is forced through them by a blowing machine. The changes effected are quite marked. Thus, while common cotton-seed oil has a specific gravity of 0·925 and a very moderate viscosity, after the blowing operation is complete its specific gravity is raised to 0·960 and the viscosity is raised in an extraordinary degree. Moreover the thorough oxidation thus effected has improved its character as an ingredient in lubricating oils in other respects. It is no longer liable to acidity when used as a lubricant, and so is especially adapted for mixing with paraffin oils for the manufacture of the best heavy lubricating oils. Numerous other uses have also been found for these blown oils, such as the manufacture of artificial leather and other products.

In the domain of the essential oils, very important discoveries have been made in the identification of the essential odoriferous constituents of several of the essential oils and the consequent synthetic preparation of these constituents. It has been established that the esters of certain alcohols of the composition $C_{10}H_{18}O$ and $C^{10}H_{20}O$ are the principal constituents of a large number of essential oils which owe their aroma in the main to the esters in question. Thus, for instance, linalyl-acetate and other esters of linalool, $C_{10}H_{18}O$, have been recognized as constituents of lavender oil, bergamot oil and petitgrain oil, while geranium oil, lavender oil and lemon-grass oil contain esters of geraniol, $C_{10}H_{18}O$, principally geranyl-acetate. In pine oils finally esters of borneol, $C_{10}H_{18}O$, have been found. It is similarly found that citral, $C_{10}H_{16}O$, the aldehyde of geraniol is the main constituent of oil of lemon and that

rhodinal, $C_{10}H_{18}O$, is the fluid constituent of oil of rose. All of these compounds of definite composition are now prepared in a pure state and are coming into use in the perfumery trade as much more reliable than the natural oils themselves.

Another interesting class of products closely related to those just spoken of are the so-called "ester-gums," recently offered to the varnish trade as substitutes for copal, dammar, mastic, sandarac and other natural varnish gums. These ester gums are the glyceryl, methyl and ethyl esters of abietic and pinic acids and are prepared by saponifying ordinary colophony resin (or common rosin) under pressure and then freeing the ester so formed from water, etc., by distillation in vacuo. The artificial gums so obtained are soluble in all the varnish-forming solvents and form varnish films of great brilliancy and durability.

In a lecture which I delivered here in January, 1892, I spoke of the chemistry of starch and the decomposition products obtained from it under the influence of the diastase of malt. The importance of the industries based upon starch and its alteration products makes this a subject of practical as well as theoretical interest. Dr. Lintner, of Munich, has recently published the results of studies made by him on this action of diastase. He considers the existence of the complicated dextrine molecules of high molecular weight, described by Brown and Morris (an account of which was given in the lecture before referred to) as very unlikely. By the aid of phenyl-hydrazine as reagent, Lintner established the presence of isomaltose as an invariable ingredient in the product of the diastatic action. By the use of four different methods of study, viz: the determination of specific rotatory power, the reducing power of Fehling's solution, the molecular weight determination, according to Raoult's method, and the addition of phenyl-hydrazine as reagent, Lintner determines that five well-characterized products can be obtained from the action of diastase on starch. These are the three dextrines already known under the names of amylo-dextrine, erythro-dextrine, and achroo-dextrine, isomaltose and maltose. Supported upon the results of the

molecular weight determination, Lintner gives to amylodextrine the formula $(C_{12}H_{20}O_{10})_{54}$; to erythro-dextrine the formula $(C_{12}H_{20}O_{10})_{18}$; and to achroo-dextrine $(C_{10}H_{26}O_{10})_5$. Brown and Morris' complex dextrines he considers to have been mixtures of these simpler dextrines with either isomaltose or maltose, as all five products of the diastatic action may exist together in the infusion at the same time.

The chemistry of cellulose and its derivatives has attracted the attention of many experimenters. Among the most important results have been those of Cross and Bevan on the new forms of cellulose obtained from what they term cellulose sodium xanthate. This is formed by treating the cellulose with a concentrated solution of sodium hydrate, and exposing this product to the action of carbon disulphide vapor. Action ensues, and in the course of an hour or two a yellowish mass is obtained, which swells up enormously on treatment with water, and finally dissolves completely. This crude solution containing yellow bye-products, yields the cellulose derivative in a pure state on treating it with saturated brine or with strong alcohol. These precipitate it either in a flocculent condition or in leathery masses which may be washed with sodium chloride solution or sixty-five per cent. alcohol, respectively. On re-dissolving in water, an almost colorless solution of extraordinary viscosity is obtained. A seven per cent. solution of the compound, *i. e.*, containing (say) five per cent. of cellulose to 100 of water has a viscosity equal to that of glycerin measured by the rate of flow. The solutions of this cellulose-sodium xanthate undergo decomposition, however, spontaneously after a time, more rapidly by heating or the addition of reagents. There separates out then a firm coagulum of hydrated cellulose, easily capable of purifying by simple washing with water. The spontaneous gelatinization of the solutions appears to take place without change of volume, the coagulum invariably reproducing the details of the surface of the containing vessel. Shrinkage then ensues, the form of the coagulum being perfectly retained. Solutions exceeding ten per cent. strength (in cellulose) give a coagulum of great solidity; even when diluted to 0·5 per cent. strength the

cellulose jelly obtained has sufficient consistency to be handled. Among the many applications of the solution or of the pure cellulose separating from it, may be mentioned the following, which have been pointed out by the authors:

(1) As an adhesive substance, replacing glue, flour-paste, gums, india-rubber solution, etc.

(2) For sizing and filling textiles. In this direction the important advantage of depositing a substance of the same chemical composition and physical properties of the textile does not need to be insisted upon. The authors in this way have introduced from fifteen to thirty per cent. of additional cellulose without the possibility of its presence being appreciated except by comparison with the unfilled fabric.

(3) For purposes of producing casts and moulds. By coating surfaces with the solution or filling hollow vessels, perfect reproduction of form and structural details can be obtained in the form of a more or less solid mass of cellulose hydrate. The cellulose when fully de-hydrated by drying, forms a transparent mass, resembling horn, which can be worked in the lathe, taking a brilliant surface under cutting and polishing tools.

(4) The applications of the various forms of the solid cellulose in block or film form are evident to any one who has followed the utilizations of celluloid or nitro-cellulose, over which this has the advantage of lack of dangerous inflammability.

One of the industries in which great changes have been made in the last few years, owing to the introduction of new chemical processes, is the tanning and leather industry. While the tanning of heavy leather has been improved by the widespread introduction of oak and hemlock bark extracts of definite and uniform composition, it is in the tanning of lighter leathers, such as calf and kid, that the greatest advances have been made. For these, the "dongola" tanning and the newer "chrome" or mineral tanning processes have almost entirely displaced older methods. The dongola process is a combination process using gambier, alum and salt together in the same liquor and following the tanning proper by a treatment of the

leather with "fat liquor," or oil emulsified with borax or soda solution.

It is, however, the successful introduction of the mineral tanning processes which is now revolutionizing the manufacture of lighter leathers in this country. The process generally in use at present involves treating the skins at first with a weak solution of bichromate of potash, to which sufficient hydrochloric acid is added to liberate the chromic acid. After the skins have taken up a bright yellow color through their entire texture, they are drained and transferred to a bath of hyposulphite of soda, to which some acid is added to liberate sulphurous acid, which reduces the chromic acid to green chrome oxide, while the sulphurous acid is at the same time oxidized to sulphuric acid, which liberates a further portion of sulphurous acid until the whole of the chromic acid is reduced. The leather so produced is of a pale bluish-green color, tough and flexible, and thoroughly resistant to water. Indeed, it is this latter property which distinguishes it from all other forms of leather, as the combination of the hide fibre or coriin with the chromium oxide is apparently more stable than its combination with tannin, and yields less to boiling water. The leather also can be dyed and produced in a variety of colors, but the dyeing must be done before the leather dries, as its water-repellent character is such that once dried it cannot be wetted sufficiently to take up a full color. The process is now carried out in this city at several morocco tanneries on a very large scale, and with perfectly satisfactory results.

Chrome-tanning processes involving the use of chrome alum and other salts of the sesquioxide of chromium as the basis of the tanning vat have been used, but apparently the combination does not take place so readily as where the chromium oxide is obtained in *statu nascendi* by reduction from the bichromate under the influence of reducing agents. Basic chromium salts have also been recently proposed as mineral tanning agents, but of their practical success I cannot speak from personal knowledge. That mineral tanned leather has taken a strong hold upon the industry was made evident by the many and fine exhibits of such leather

at the recent Columbian Exposition, and can also be gathered from the testimony of foreign experts who visited this country during the past summer. Prof. Henry Procter, of the Yorkshire College, Leeds, England, in a lecture delivered since his return, says of the chrome process that "it may be said to be the most striking new departure in tanning which has taken place within my memory."

With this brief and partial survey of the field I will conclude, simply drawing attention to the fact that we will have the pleasure this winter, in our course of lectures, of hearing several of their subjects taken up in detail by eminent specialists.

The Lumière-Lippmann Color Photography.

By F. E. Ives.

[*Read at the stated meeting of the Institute, held Wednesday, Nov. 15, 1893.*

In the spring of 1892, there were exhibited in the Photographic Exhibition in the Champ de Mars, in Paris, photographs, by the Lippmann process, of a parrot, a branch of holly, pieces of colored glass, etc., which M. Alphonse Berget and others declared were true reproductions of the colors of the objects. I could see in these photographs only the colors of thin films, metallic and changeable as such colors usually are, and in some instances not even confined to the colored objects themselves, but spreading over objects that were uncolored in the original. These pictures were also devoid of either whites or blacks, the high lights of the objects being rendered more like blacks than the shadows. Others, notably Mr. Cameron Swan, who wrote a letter on the subject to the *London Times*, noticed the same defects in these photographs, and Captain Abney, who had experimented with the process, found that by varying the time of exposure he was able to make a blue photograph with red light, and *vice versa*, and a colored photograph with white light. It was generally admitted that the results obtained by Profes-

sor Lippmann did not sustain the claims made for the process; and when it was announced, this year, that the brothers Lumière had succeeded in so far improving upon Lippmann's method as to obtain really satisfactory color photographs of natural landscapes, those who had seen the photographs for which such extravagant and inaccurate claims were made a year before, were naturally and very justly skeptical.

Now, however, the Lumière photographs have been shown in London, and although there is still a certain amount of mystery surrounding them, it is possible to form a truer estimate of their character and importance, and to make an intelligent comparison with another and more successful method based upon quite different scientific principles.

The Lumière photographs are about three inches square, and by light reflected from their surface at most angles, they have much the same appearance as the French albumen process lantern positives, the high lights of the picture looking like clear glass and the shadows having the appearance of an albumen or gelatine film filled up with a dense, dark-colored deposit of silver. It is said that by transparency they are negative images; but those shown are sealed up so that they cannot be examined by transmitted light.

Unlike Lippmann's photographs, these examples show color only when the light is reflected from the surface at one particular angle, and for that reason the colors are not "changeable." This in itself is really a very important improvement, although it carries us further away from, instead of nearer to, the popularly desired conditions in color photography. It is, indeed, a significant fact that real and undoubted improvement intensifies instead of lessening a characteristic defect of the original Lippmann photographs, which some writers have not hesitated to say would "undoubtedly" be overcome, namely, the inability to see the colors at all angles.

If the pictures were uncovered the critical angle would undoubtedly be perpendicular to the surface of the plate; but it would then be necessary to provide some means for

illumination and vision in precisely the same direction. It is also necessary that the source of light be large enough to illuminate the entire surface of the photograph equally with parallel rays coming from it. A rough approximation to these conditions is secured by covering the picture with a shallow prism, and then examining it by the reflected light of a sufficient exposure of even white or gray sky, holding the picture at nearly arm's length away from the eye. More satisfactory results could doubtless be obtained by means of a special device, which could be used like the stereoscope or photochromoscope. It would be quite easy in this way to exactly fulfil the theoretical requirements for illumination and vision, and at the same time to magnify the picture, which must now be made to occupy only a very small angle of vision in order to be seen all at once.

The pictures are also projected upon a screen by means of the megascope or aphengescope lantern, and in the absence of a special device for examining them by daylight, this is the only really satisfactory way of seeing them. It is, however, necessary to employ a powerful electric arc light in order to project them with satisfactory brilliancy up to even two feet diameter, as compared with ten feet or twenty-five times greater area, for the photochromoscope pictures with the same light.

Seven pictures were shown at the Photographic Congress, and at the Camera Club: four landscapes, two portraits with accessories, and one reproduction of a chromo-lithograph, a rather poor result, the original of which was not shown. Unlike Lippmann's photographs, they rendered the deepest shadows black, and the high lights white, and showed many delicate shades of color which impressed the spectators as being something more than the ordinary colors of thin films. One of the landscapes was beautiful, although the foliage appeared to be that of autumn, and it was understood that the photographs were made in early summer. In parts of some, the chlorophyl green was fairly well represented, but in others, where autumn foliage was not suggested, the green was raw and metallic. The red of a tile roof looked dull and faded, the blues of the skies were criti-

cised by some of the spectators, and the flesh in the portraits had an unnatural purplish hue; but in my opinion these defects are only such as one ought to expect, from the manner in which the process was carried out, even assuming that it be really capable of making accurate color reproductions if carried out in a thoroughly rational manner. From a theoretical point of view (and it follows, from a practical point of view,) it is not reasonable to expect that a mixed color like chlorophyl green will be accurately reproduced on a plate not sensitive into the red of the spectrum below the first absorption band of chlorophyl or which is disproportionately sensitive to that red as compared to the sensitiveness to green. In the first case, the green rays only would act in producing the picture, resulting in a raw, metallic color, and in the other case the red rays would act too much, or the green too little, and result in a brown or red hue, suggestive of autumn tints. Flesh color, if the plate be disproportionately sensitive to blue, and not sufficiently corrected by yellow screen, must take on a purplish hue, or if over-corrected by yellow screen, a yellow hue must result. It follows that the plates must not only be sensitive to all colors, but the sensitiveness must also be properly distributed along the spectrum, or, what amounts to the same thing, must be modified by the use of a quantitatively selective color screen, made up and adjusted by experiment in photographing the spectrum itself, just as I have for years made selective color screens for carrying out the photochromoscope process and for orthochromatic photography until the spectrum photographs correspond to the spectrum itself in the relative visual intensity of the different colors. Until this is done, it is not reasonable to expect that delicate shades of compound colors will be accurately reproduced by any process. It would appear from this that by no evident possibility can this method ever possess any advantage over the photochromoscope process in the matter of accuracy, because in both cases it depends (admitting every possibility for the Lumière-Lippmann process) upon the relation of sensitive plates and color screens, which must be regulated in the same way for both processes.

One of the most remarkable things about this Lumière process is its rendering of blacks and whites. According to Lippmann's theory, the blacks should be rendered by clear glass, and the whites by a film filled up with laminæ of deposit which would reflect light of every wave length. In short, the greatest amounts of deposit and opacity would be in the whites of the picture, and the smallest amounts in the blacks, as in an ordinary photographic negative. I have already observed that the Lumière photographs when seen by ordinary reflection resemble a positive instead of a negative. It is further remarkable that the greatest amount of light reflected from these photographs comes from the parts which look like clear glass, and that even this amount, which makes the whites of the picture, is only equal to the reflection from a black glass, or the surface of the gelatine film itself. The shadows appear black, not because there is no deposit there (in which case the deepest shadows of the picture would be as "white" as the high lights in the examples shown), but because the glass is obscured by a deposit so heavy and matt that it scatters the light striking upon it, instead of reflecting it straight back at the critical angle. In other words, we appear to have a positive where we are told that there is a negative; if this be true, is the positive the result of a "reversal" of the image by the long exposure, and, if so, is this reversal one of the conditions of success?

Does not this image built up by photographic action upon the sensitive plate act by a process of substraction from the white light, which would otherwise be reflected from all parts of its surface alike, instead of by reflection from internal laminæ in the manner assumed by Lippmann?

Lippmann's theory, as I understand it, calls for a different series of laminæ within the film for every wave length of light, amounting, where white light acts, to over 30,000 laminæ in a film no thicker than a single wave length of red light! Would not such a series of laminæ reflect a great deal of light instead of adding nothing whatever to the normal reflection from its surface, which is all we appear to have in the examples shown? Cannot every color actually

shown in the Lumière photographs be reproduced by means of a single interference film of varying thickness, backed up and broken by a granular deposit of varying density? Have we anything more than this in the Lumière photographs?

It seems reasonable to suppose that the long exposure given to these plates would produce a reversal of the image. The dense deposit in the shadows might result from the action of scattered light in the camera, or to preliminary exposure, or to the use of a too active developer, or to any or all of these causes combined. May we not be given an opportunity to learn the truth, in order either to prove Lippmann's theory, or to formulate a new and more rational one?

At first glance, it would appear that an examination of the Lumière photographs by transmitted light might yield an answer to all of my questions, by showing that the image is really a negative one; but it is not even necessary, in order to explain the "whites" of these pictures, to assume that the image is positive throughout, but only that there is a superficial reversal, just sufficient to prevent the production in development of a deposit superficial enough to obscure the normal surface reflection of the gelatine film.

I have some hesitation in putting forth views which a more thorough examination of the Lumière photographs might lead me to modify; but since such examination is forbidden, I can only hope that the questions which I raise may help to bring about such a thorough investigation of the subject as its importance demands.

In conclusion, it is worthy of note that the Lumière-Lippmann process, whatever its capabilities as to accuracy may prove to be, when it is carried out according to theoretical requirements, is necessarily subject to limitations similar to, and in some respects greater than, the already successful photochromoscope process. which is carried out with commercial sensitive plates and ordinary development. Knowledge of this fact, which cannot be gainsaid, will doubtless lead many people to take an active interest in the friendly rivalry which promises to attend the further development and application of the two methods.

A PLEA FOR THE STUDY OF ELEMENTARY FORESTRY IN THE LOWER SCHOOLS.

BY EDWIN J. HOUSTON, PH.D.

[*A lecture delivered before the Franklin Institute, November 3, 1893.*]

MEMBERS OF THE INSTITUTE, LADIES AND GENTLEMEN:

It is with no little hesitation that I advocate what at first sight may seem to necessitate the introduction of an additional study into the curricula of our lower schools. Already these curricula are overcrowded. So many studies are demanded of our younger children that their minds are bewildered as they are necessarily hurried from one subject to another. Before new ideas have sufficient time to develop they are disturbed and displaced by disconnected and not infrequently irrelative ideas so that neither become factors in the child's mental development.

The tendency of the best methods of education is to simplify and unify these studies; not to increase their number. Unless, therefore, I can show that such introduction is along these lines I acknowledge that my proposition is unwise. But I believe I can show that my proposition to introduce the study of forestry into the lower schools does not necessarily tend to increase the number of studies, but rather to unify existing studies. The present is a time of marked advance in educational methods. The incorrect or utterly bad methods of the past are rapidly being replaced by more correct and advanced methods, and the educational future appears bright and promising.

But I think that in this as in all reform movements there is a danger to be apprehended. We should take time to make haste slowly. In all reform movements besides the true reformers there are invariably to be found many who insist on associating themselves with the movement without exactly comprehending its significance. Such people delight

in posing as reformers. Seeing old ideas or methods attacked it is sufficient, in their misguided judgment, for a thing to be old to place it among the things needing reform. It never appears to enter into the minds of such would-be reformers to enquire whether the thing they desire to reform has any element of good in it. To them the fact that it is old, is sufficient to stamp it as bad and needing reform.

Such reformers seeing poor results produced in a particular line of work, especially if it be in their own line, are apt to ascribe the failure to any other cause than to faulty performance. It never seems to occur to them that the fault may lie in themselves. They look for it rather in a faulty system or in any but the true cause and, therefore, clamor for a reform of the system when they should honestly labor to reform their manner of applying the system.

I think this is especially true in the reform movement in educational matters that has accomplished so much good and that promises to do so much in the near future. The past few decades have unquestionably witnessed marked improvements in educational methods. But along with the good has come much unmitigated evil. Together with the true reformers in this work, whose object has ever been to retain that which is good and to reform only that which is bad, are to be found not a few others who are desirous of reforming everything except themselves. Such would-be reformers, unable to appreciate the inestimable value of those golden educational principles that have required centuries of experience to acquire, have entered into the Holy of Holies in the Temple of Education and have not hesitated to lay their sacrilegious hands on all that comes before them. So many changes have thus unwarrantably been introduced into educational systems as new and improved methods that they threaten, in many respects, to render the new or reformed system less intelligible and practical than the old. Indeed, from my standpoint as a teacher, I think that not a few of the so-called improved methods, recently introduced into our educational systems, are such

unmitigated evils as to call for immediate and complete abolition.

Such a state of affairs is, perhaps, to be expected where the necessary reforms have been far- and wide-reaching. The educational methods of our forefathers, and indeed, the methods existing in the school days of those I have the honor of addressing, I think all will acknowledge, contained many things that sadly needed improvement; but, I feel sure I can confidently appeal to your judgment as intelligent people, whether there was not also in these old methods, much that has unfortunately been swept away in the false portion of the reform movement, which could profitably be re-established.

I repeat, therefore, that, appreciating as I do, the extent to which the false and worthless have been introduced into our educational systems under the guise of reform, I feel no little hesitation in placing myself in the position of advocating what may at first sight seem to be, and what to a certain extent is, the introduction not only of an additional study into the curicula of our lower schools, but also of a study of so difficult a nature as forestry.

I believe, however, I can convince you that though the study of elementary forestry be introduced into our lower schools, yet considering its necessarily limited scope there would not thereby be necessitated so much, the introduction of a new study, as a better and more logical distribution of the studies already established.

I would recommend the introduction of forestry as a branch of elementary natural science. Fortunately, there is no need at the present time for an extended plea as to the wisdom of introducing science studies into even the lowest of our schools. It is so generally acknowledged that natural science possesses marked educational values that I think the wisdom of introducing it early in the school course will be readily conceded.

For my part, I believe that science studies should not only have a place in the earliest portions of the child's school work, but that they should form the bulk of such work. I will state somewhat in detail my reasons for this belief.

because I feel that if I can establish this principle beyond a peradventure, I will have gone far towards justifying my plea for the introduction of the elementary study of forestry early in the school work.

For general purposes of classification, I would arrange the studies suitable for the first year of the child's school work under the three general heads of Natural Science, Language and Number.

Did I desire to make a still broader classification I would make natural science the basic study in the first years of the child's school life, and language and number branches of science studies rather than separate studies.

My reasons for such an arrangement are as follows: I believe that nearly all the child's early schooling should consist in teaching it carefully to observe what is happening around it. Such happenings must necessarily consist mainly in ordinary natural phenomena, the causes and effects of which can only be intelligently studied under natural science. I do not care especially what particular branch of natural science is taken as the starting point. I believe that to be the best system of primary education which attempts to develop the child's mind from observations made by the child itself; which, instead of attempting to instruct the child by repeated statements of glittering generalities, leads it to observe the things around it and to ask questions concerning their causes and effects. Such a method makes the object of its studies the things which actually come under observation by its senses; *i. e.*, things it can actually see, handle, smell or taste, rather than abstract things of which it can generally form no definite ideas.

I would give the child its earliest lessons in language from descriptions of the natural objects it has observed, teaching it carefully to describe, in its own language, the impressions or ideas which such observations have produced on its mind, guiding and directing, to whatever extent may be necessary, the language with which it clothes such ideas. According to this method in the first part of a child's school work, language would not be made a study

separate and distinct in itself, but merely a branch of that basic study—natural science.

I would, in a similar manner, teach the primary ideas of number: never attempting to deal with abstract ideas, but invariably employing actual things the child observes, and preferably things that it can readily handle.

Since the things the child would thus observe, necessarily form portions of the earth's surface, being as they are the various things it sees on the land, in the air, or in the water, I believe that the basic study in primary education should be the study of natural science as centred in and forming a part of elementary geography.

I do not mean by this the geography which I fear is still taught in many of our schools, but the new and properly reformed geography, which I am glad to say is rapidly gaining ground among thoughtful teachers. I would base the child's earliest lessons in geography on its personal observations of natural phenomena; not of phenomena in some distant or remote corner of the earth, inaccessible to the child, but in that exceedingly limited part known to the child from living on it. In other words, I would advocate at the start not the study of the earth as a whole, but the study of that part of the earth which forms the child's home surroundings, or what the Germans call *Heimatskunde*.

I think, however, it would be a mistake to keep the child too long on the study of natural phenomena in the immediate neighborhood of its home. We must not forget that the wonderful recent improvements in methods of transportation and in means of communication, either by the telegraph and telephone, or by the printed page, have made our earth very small; or, if you prefer so to state it, have greatly extended the sphere of home surroundings. The *Heimatskunde*, therefore, so far as geographical studies are concerned, can, very early in the primary course, become the *Erdkunde;* viz., the earth as a whole, and I quite agree with Krapotkin, in his recent admirable address to the Teachers' Guild Conference, at Oxford, that from this stage onwards; viz., through all the remaining grades of the

primary, the secondary and the higher education, the *Heimatskunde* and the *Erdkunde* should in geographical work be carried on in parallel lines.

While I think the primary education of the child should thus be founded on the study of natural science, yet I am aware of the fact that a danger exists in this method, which should be zealously avoided. It is briefly this: Do not permit the child's observations to become disconnected and haphazard. Do not permit the child to accumulate a heterogeneous collection of facts that have no connection whatever. If early scientific information is to possess any value, it must be systematized. For this purpose intelligent supervision of the child's observation will be required, and here an opportunity will be afforded for the best work of the teacher.

So far as the early study of geography is concerned, I believe it to be of great importance to impress on the child's mind the fact that all the observations it is making have a special bearing on the character of the earth's inhabitants. In other words, that just as all natural science tends or should tend to render the life of man more comfortable, happier and better, so all the study of geography tends or should tend to the earth's master—man.

If these facts are constantly kept in mind all elementary work in natural science will of necessity take the form which all truly scientific work must take; viz., a systematized form as opposed to a disjointed and disconnected form.

The methods I would recommend in the study of elementary natural science are, therefore, based on the fundamental principle that the child is to be kept in touch with nature, rather than in contact with books; is to be asked to observe what it can touch, taste, see or hear, rather than to attempt to describe, much less understand, things it never has seen and probably never will see. It is evident that these two things are as different as light is from darkness, and are as widely separated from each other as the east is from the west.

But after the child has for some time studied natural phenomena by means of personal observations on objects

actually seen or handled, there is a means by which its field of observation may profitably be extended to embrace things it can neither actually see nor handle, and this is by bringing them before it through pictures or photographs. Where such pictures or photographs are reliable they may afford great aid to an intelligent child. They can never, however, possess an educational value equal to that of the objects themselves, since mere pictures or photographs must to a great extent fail to possess the vividness of outline and color of the real objects. Pictures and photographs form, indeed, a species of books the use of which it is the very object of the new method of education to escape. They should be employed to supplement the actual things only where the actual things are unattainable. I would, therefore, employ pictures or photographs with care during the early school work and even here, only after the child has performed considerable work without such aid.

The practical teacher should ever be on the alert to lead the child's mind along lines for which it shows a decided preference; provided, of course, such lines appear desirable. In this connection advantage may well be taken to put to use the desire so common in children to make collections. All children possess this desire: and, at some time or other, all will collect. It may be only dirt or mischief, buttons or stamps; but if intelligently directed, this collection may be one or another of the many things which go to make up a natural history collection; minerals, insects, butterflies, flowers, leaves, etc. Start children collecting; and, if you have never tried it before, I am sure you will be agreeably surprised at the intelligent, even enthusiastic, interest you will thus awaken.

If the early lessons in the school room are based on what the child actually observes there will be no lack of interest in its school work. Talk to any intelligent child about simple natural phenomena in such a way as to interest it, and I am mistaken in my experience with children if you will not have a torrent of questions poured into your ears, that will cease rather from your ability or willingness to reply to them, than from the child's stock and trade in such things

being exhausted. Should we not as intelligent people take a hint from this characteristic of childhood, improperly called inquisitiveness, but in reality indicative of a true thirst for knowledge?

A danger exists in all educational work, but especially in the case of younger children, of failing correctly to understand the principles taught. Josh Billings has very aptly remarked, "It is better not to know so much, than to know so many things that ain't so."

This difficulty, so quaintly described by Mr. Billings, is especially liable to occur either when an attempt is made to teach abstract facts to immature minds, or when the teacher is not thoroughly acquainted with the subject.

Apropos of this latter, I remember some time ago a statement in one of the newspapers, which, though intended to laud the teaching of science to young children, nevertheless, to my mind, formed a striking instance of the dangers that sometimes lurk in such teaching. The article cited the case of a teacher, who, during a walk with some children, adroitly led them to ask questions about the telephone and then followed it by a lesson intended to impress broad scientific principles on their minds. This lesson was so full of inaccuracies and misleading statements that it necessarily laid up for some future teacher, the difficult task of removing such ideas. Though I would teach science to young children I would see zealously that the teachers themselves are first thoroughly instructed in what they are expected to teach.

Impressions made during early childhood are the strongest. The child's mind is then highly plastic; its receptivity is at a maximum. Any false teaching at this stage is most difficult afterwards to remove. It is the best of teachers, therefore, that are required for primary work; not tyros in the art, but veterans.

Let us, therefore, along with the University Extension work that is now being so ably carried on, organize means for properly training teachers in such work, not only by means of lectures and laboratory work, but especially by the very means on which we are so insistent in the case of

children: namely, by bringing the teachers into contact with nature rather than with books; or, in other words, by actual instruction in the field.

I am pleased to say that an earnest and intelligent effort is already being made in Philadelphia to remedy this defect, by means of which opportunities are offered to all who wish to render themselves fit to become science teachers.

I think I know the question that has already suggested itself to your minds; namely, How can we reasonably expect that so difficult a study as the science of even elementary forestry can be comprehended by the children in the lower schools, when, as is well known, so many of the principles of the study are difficult of comprehension even by cultivated adult minds? Did any intention on my part exist to recommend teaching these abstract parts of forestry, I acknowledge that there would be thus added another to that already too extended list of studies, so much of the information derived from which would come under the ban of Josh Billings' criticism.

But while there is much in the science of forestry that is abstruse, there is also much that is wonderfully simple. I would, of course, limit the teaching of forestry in the lower schools to these simple portions. The rest should be relegated to the high school, the college, or the university.

I will give in detail a scheme of such study of elementary forestry as I would recommend for the lower schools as soon as I have briefly stated my reasons for believing that this study should be taught at all.

I do not belong to that class of teachers who believe that the strongest argument which can be urged in favor of placing a particular study on the curriculum, is to be found in its practical character; at least, not in schools short of the high school, the college, or the university. To my mind the cultural or disciplinary values of a study are often of far greater importance than its practical value. I believe that the main object of all education can be embraced in teaching the child three things; namely,

(1) How to observe.

(2) How correctly to draw conclusions from what it has observed.

(3) How correctly to express in spoken or written language the conclusions thus drawn.

If in addition to this, a study possesses a practical value, its value must, of course, to that extent be enhanced; but I do not believe that even in this case its main value lies in its practical character.

There is, however, an additional object in education during the child's school life; there are certain social and moral duties, on which, I believe, it is the function of the school to insist; viz., sobriety, honesty, purity, industry and integrity. These should be clearly impressed on the child's mind, not only in the home, but as well in the school; moreover, the child should in addition be taught the duties it owes to the family, to the school and to society in general. The child should be taught briefly the character of the laws of the country in which it lives as well as the character of the laws that govern natural phenomena.

If then it can be shown that in order properly to teach the child such duties, there must be introduced what appears to be an additional study, a valid reason would thereby be established for such introduction; provided, of course, the requirements of such additional study, in point of time, are not too great. I think I can on this ground, with propriety, recommend the introduction of a study of elementary forestry into our lower schools.

It is curious how great is the ignorance or indifference of the general public, as to the character and extent of the effects produced on a country by the removal of its forests.

The many evils which follow in the wake of the destruction of an extended forest cover are thoroughly recognized by thinking people. There is no question as to the general character and the extent of these evils, nor as to the loss of money to the country in which they occur. There can be no doubt that the interests of nearly the entire community demand that the forests should be protected by the enactment of penal laws, but, notwithstanding this necessity, either a stolid indifference or a wicked ignorance on such questions exists on the part of the public.

[*To be continued.*]

PRACTICAL RESULTS ARISING FROM THE USE OF SAFETY DEVICES APPLIED TO MACHINES.

BY JOHN H. COOPER.

Much has already been done by the ingenious inventor and the careful manufacturer to prevent accidents to workmen, whose duties require them to be constantly attending to and handling machines.

To state here that a steam boiler, whose overcharge of steam pressure would prove very disastrous were it not supplied with an automatic safety valve, is not news for this journal, nor is it original information to tell of check and relief valves applied to pipes where escape of water from a steam boiler, or where the bursting of pipes and vessels would result from their inoperation or absence. These things have long been used with good results, as invariable as their application.

To the moving cages and platforms of passenger elevators and to all hoisting machines—such dread sources of accident—the application of "safety catches" has been regarded as absolutely necessary; indeed, no first-class "elevator" is now run without means of security against disaster by falling.

In cases where breakage of the machine is imminent from the nature of the work to be done, and the circumstances of use, a serviceable part of the machine is designed to receive, what might be called a safety or a "breaking piece," of trifling cost, which will hold the parts in proper working place during all regular work, but which will yield to unusual strain and give warning of failure.

Instantaneously acting stop-motions, such as are applied to card-making machines, to weaving looms, and the like, for effecting a sudden stoppage of all working parts when the card wire has gone astray, or when the tardy shuttle has failed to pass the web; these are familiar illustrations of means for protecting the machine against serious breakage.

Usually, all parts of the machine itself are designed for harmonious action and for the production of a specific effect; nothing is left to chance. Its whole causation is intentional. If there be any lack, it exists in the region of approach between the machine proper and the operator, who may not always be on the alert. Something is needed to supply the deficiencies of human thought, or watchfulness; to serve as prompter or guard to the human hand, at the point of danger.

We are safe in saying that no machine can be called perfect, if not adapted in every particular to the needs of the operator, since the machine cannot be run without him. He who uses and guides it should have safe and efficient *handles*, so to speak, whereby he may approach and manipulate it safely and effectively, without danger to himself or injury to the machine. It is all very well to say, "beware;" "take care of yourself;" but the cheapest way in the end is to provide the safeguard and thus protect the operator. As new "hands" are coming into mills all the time, who are presumably ignorant of the dangers surrounding them and of the constant care which is necessary to be exercised over their persons at all times, and so may inadvertently meet with accident, it is certainly most important to perfect the safety elements of machines, as well as to enjoin all in observance of the usual plainly written and conspicuously posted rules.

Experience has shown that a great number of accidents is caused through loss of presence of mind by the eagerness of work-people to get through their work expeditiously, under threat of punishment, if they do not. The largest contributions to the list of accidents, it is said, are amputations and maimings of dexter hands, due to this eagerness. If urging must be done, these results call loudly for safeguards and warning mechanism, and the enforcement of stringent rules for safety.

Fortunately, we are not bound by the ancient law of the Hindoos, who wrote: "Under pretext of care for the creature, their authors imposed the fatal principle, that a

man must not address himself to discovery or invention, as Heaven had provided him all things needful."

It is bad enough to have machines breaking down frequently, but the loss of an operative's hand or life is a more serious matter.

"What would one not do to save the life of a fellow-creature, and how heart-rending it is to find ourselves compelled to be an impotent witness of an accident to a human being! Should we not, therefore, adopt all possible precautions to prevent these accidents, often so terrible, which pass unnoticed only on account of the very frequency of their occurrence?"

These words were penned by a committee of the Industrial Society of Mulhouse, in Alsace, which has devoted the past twenty-five years to the invention, application and publication of appliances and apparatus for the prevention of accidents in factories.

The subject is a broad one, possessing commercial as well as humanitarian importance, either phase of which should commend itself to our earnest attention.

A critical investigation of most accidents has proved that they might have been avoided by an early application of means, which in many cases would have been attended with little expense.

Knowing this, it is safe and timely to re-state the warning words which have been formulated by the committee referred to above—"Indifference to such matters is furthermore no longer admissible. It is all the less pardonable, as here, contrary to the circumstances of ordinary life, the rescue is effected without personal danger of any kind"—the writer means to say that the device may be planned in the inventor's study and applied to the machine during the ordinary processes of its building.

After what has been said on the evident necessity of avoiding accidents to workmen, because of the certain threefold loss to the community where they occur, it appears plain enough that to argue the need of such care-taking would be as throwing words away, and whatever may be said for or against the objects of this society, it has

lived to see its labors crowned with success ; therefore, we may unhesitatingly ask our readers to consider these matters and to interest themselves also in the invention and application of them wherever they can be of service, remembering ever, that we owe our workmen other things than the wages given to them, as Mr. Dollfus said, a score of years ago, and among these may surely be named absolute personal safety from the moment they enter our factories and service.

The cause of labor is a common cause, and its benefits are reciprocal. Accident to an operative of a machine may result in irreparable damage, as, for instance, the loss of a skilful hand which may be indispensable to an important industry; on the other hand, the evils arising from bad advice or misdirected training may in time, by proper instructions with renewed effort, be entirely overcome, restoring the man to future and to better usefulness, while the hand severed from a good right arm, the obedient instrument of a well-ordered, commanding brain, is lost forever—lost not only to the owner thereof but to his employer and to the community.

If as Bacon says: "Education consists in removing the difficulties of the mind," and we are made many times aware of the expense and effort to accomplish this in our plentitude of technical schools established among us, believing that we will realize great gain from them, may we not expect advantages by efforts made towards persona safety in the use of machines, not only by giving instructions how to avoid being injured while using them, but in the application of accident-preventing devices, or what is better, to so construct mechanism that accidents to the machine and to the man may be reduced to the least possible number?

With the exercise of ingenuity and care for protecting the machine against injury to itself, the attendant may be protected also, and if proper safeguards be thrown around a machine, with ordinary care and training that may be given, the attendant can perform all the work necessary about and with the machine, with perfect safety to himself, thus preserving machine and man; while the employer, who

may be held responsible for accidents occurring from exposed machinery which might have been protected at little cost, will have performed his whole duty.

Securing safety to the workman is clearly within the pale of engineering. It is just as commendable and desirable a proceeding as safety in the vehicle, securing immunity from disaster to "myself and family," so to speak, when we travel about home, or go abroad; and what a comforting sense of relief to the mind it is, to know that means are being regularly devised whereby accidents are greatly reduced in number and severity.

Whether American factory operatives are more or less the victims of accidents while running their machines than those of foreign countries is probably not known. It would therefore be interesting and profitable to have some well accredited statistics in this particular, whether the American operator of machines, as compared with his co-workers in other countries, has secured a large immunity from personal injury during service, which we may assume would result from his superior intelligence, independence and capability of care-taking. Indeed, we ought not to be satisfied with our methods until we have thrown the search-light of inquiry upon every running machine in the going of which accident may happen, and possibly a human being mutilated or incapacitated permanently for work.

We should be encouraged in this proceeding from its humanitarian possibilities, because good work has already been done as evidenced by the report about to be given; for the reason, it must be remembered, that profit attends the regularity and continuousness of processes, when not interrupted by the excitements incident to disasters, and for the comfort and confidence enjoyed by all when the liability to accident is removed alike from machine and man.

After this introductory, I need not apologize for offering the following report, just received, upon the results of systematic inspection and the enforcing of means for preventing accidents in factories.

The writer is indebted to M. M. Engel-Gros (President of the Association for Preventing Accidents in Factories, Mulhouse) for the following:

Note on the statistics of accidents in Alsace-Lorraine, taken from the official reports of the Imperial Insurance Office of the Empire of Germany, for the year 1887.

The Association of Mulhouse for the Prevention of Accidents in factories has been in existence nearly twenty-five years. It is indisputable that the inspections to which it submits the affiliated establishments have borne their fruits. It is recognized that many accidents, notably the gravest, have become less frequent, and we are agreed in saying that about fifty per cent. of the accidents have been avoided. But it is difficult to estimate, by means of figures furnished by the statistics, the positive results of the inspection, in order to form an idea, as exact as possible, of the number of accidents which have been prevented. Such an estimate is possible only by a comparison of the statistics of Alsace with those of other similar industrial countries in which the prevention of accidents has not yet been applied.

It is these statistics which have been wanting until now. When one seeks in effect to estimate the number of accidents occurring in an industrial region, one meets with many and great difficulties. There exists in many works, notably those which concern insurance against accidents, reports which have served to draw some conclusions. Some have been gathered in the hospitals, others have been collected by researches made in the establishments, or near insurance companies; the Association of Mulhouse from its foundation, has published each year a report of the accidents which have been brought to the knowledge of its inspectors, but all these statistics, while they have served to guide and instruct those who have established them, could not be utilized for a serious and comparative study; some, indeed, only mention serious accidents, others confound the most insignificant accidents with those which have brought prolonged or permanent incapacity for work, without its being certain that all cases are mentioned.

The first definite reports in this order of facts have been furnished by the Imperial Insurance Office of the Empire of Germany, which published, in 1890, a very well made *statistique* of the accidents of the year 1887.

This *statistique* is rigorously exact. It does not apply to all the accidents of which the declarations have reached the professional associations—declarations which are more or less conscientiously made for less serious accidents—*but only to those which have entailed incapacity for work for more than thirteen weeks; to those, in a word, which have provoked inquiries and the intervention of professional associations.* This *statistique* is, beside, well made in order to establish a comparison between Alsace and Germany, because in 1887 the influence of the law upon obligatory insurance was scarcely yet felt, while in Alsace the preventive association has been making its inspections for almost twenty years.

Here are the principal indications which may be drawn from this *statistique*.

The number of persons insured in all Germany during the year 1887, 3,861,560; the number of accidents resulting in incapacity for work for more than thirteen weeks, 15,970; that is, 4·14 accidents per 1,000 insured.

In Alsace-Lorraine the proportion is less than in all the industrial countries of Germany.

The number of persons insured in Alsace during the year 1887, 148,221; the number of accidents resulting in incapacity for work for more than thirteen weeks, 440; that is, 2·97 accidents per 1,000 insured, and a difference of 1·17 per 1,000 compared with those in Germany.

Thus, if in all Germany the conditions had been the same as in Alsace; if the precautions had been taken there as in this country, they would have avoided:

$$\frac{3,861,560 \times 1 \cdot 17}{1,000} = 4,518 \text{ accidents.}$$

The proportion of 2·97 per cent. applies to all the industries of Alsace and Lorraine; it includes therefore not only the textile industries, but also the industries of iron and steel, mines, buildings, wood-working and of flour mills, etc., of which some have been more dangerous than the textile industry (especially metallurgy and mining), and upon these latter industries the private inspection of the Association of Mulhouse has had no influence.

If we wish to make a still more exact comparison, only the figures which are given for the *statistique* for the textile industry must also be given. (The workshops of construction might be added to that, but the comparison would be less rigorous, because the great establishments only had subscribed to the association up to the time of the enforcing of the law of obligatory insurance.) As out of 1,000 workmen insured in Alsace, 398·1 are occupied in textile industry, this proportion is still sufficient to permit a comparison with other industrial centres.

On the other hand, the influence of the Association of Mulhouse has been exercised especially on accidents to machines, because it is difficult to reduce the number of the accidents due to the slipping of persons, to the fall of objects, to horses and carriages, etc. A rigorous comparison should then include only the accidents caused by certain kinds of machinery in the different countries.

As the above *statistique* does not permit the making of a similar comparison it was necessary to apply to the Imperial Insurance Office at Berlin, which has kindly sent a copy of all the declarations of accidents of more than thirteen weeks of incapacity, for the year of 1887 in the textile industry. As to the number of workmen employed in the different industries, this appears in the *statistique* published by the Imperial Office in 1885. We have extracted from these reports the figures relative to the spinning of cotton and of wool and to power loom weaving, choosing among the declarations all those which concern the accidents occurring to machines employed in spinning and to weaving looms, for the latter only accidents by leaping of shuttles have been taken into consideration.

TABLE I.—SPINNING OF COTTON AND WOOL.

COUNTRIES.	Number of Establishments.	Number of Workmen.	Number of Workmen per Establishment.	ACCIDENTS OCCURRING TO				
				Beaters, Willows, etc.	Cards.	Spoolers, Flyers, Combing Machines.	Self-acting Ring Throttles.	Accidents Total.
				per cent.	*per cent.*	*per cent.*	*per cent.*	*per cent.*
Prussia, ...	710	33,602	47·3	20 = 0·59	73 = 2·17	38 = 1·13	44 = 1·34	175 = 5·21
Saxony, ...	241	18,681	77·5	9 = 0·48	33 = 1·76	23 = 1·23	37 = 1·97	102 = 5·45
Bavaria, ...	100	15,556	155·5	6 = 0·38	9 = 0·58	10 = 0·64	11 = 0·71	36 = 2·31
Wurtemberg, . .	86	6,897	80·2	6 = 0·87	10 = 1·45	9 = 1·30	5 = 0·72	30 = 4·35
Other countries of Germany, . . .	119	8,976	75·4	3 = 0·33	9 = 1·00	6 = 0·66	10 = 1·11	28 = 3·12
Total, ...	1,256	83,712	66·6	44 = 0·52	134 = 1·60	86 = 1·02	107 = 1·27	371 = 4·43
Alsace-Lorraine, .	94	26,011	277·6	4 = 0·15	15 = 0·57	14 = 0·53	17 = 0·65	50 = 1·91

In this branch of the textile industry there have been in Alsace, 1·91 serious accidents per 1,000 workmen insured, while in the rest of Germany there have been 4·43 per cent.; that is, 2·26 times more.

If in the spinning industries of Germany they had taken the same precautions as in Alsace they would have been able to avoid 4·43 — 1·91 = 2·52 per cent. accidents; that is, 210·9 accidents.

According to the *statistique* of the Chamber of Commerce of Mulhouse for the year 1889, there were, at this time in Germany, 4,392,821 spindles for the spinning of cotton and wool, of which 1,348,473 in Alsace, and 3,344,348 in the other regions.

If we compare the number of accidents to these, we find: 111 accidents in Germany per 1,000,000 spindles; 37 accidents in Alsace per 1,000,000 spindles; that is, 0·24 per cent. in Alsace, against 0·50 per cent. in Germany, which makes a difference of 0·26 per cent., or 36·5 accidents which could have been avoided.

TABLE II.—POWER-LOOM WEAVING.

COUNTRIES.	Number of Establishments.	Number of Workmen.	Number of Workmen per Establishment.	Accidents by leaping of shuttles and weaving looms.
				per cent.
Prussia, ...	984	78,815	97·7	39 = 0·49
Saxony, ...	357	30,365	85·3	19 = 0·62
Bavaria, ...	64	7,873	123·0	4 = 0·50
Wurtemberg, ...	39	4,786	122·8	2 = 0·41
Other countries of Germany, .	186	20,073	107·9	7 = 0·34
Total, ...	1,630	141,912	87·0	71 = 0·50
Alsace-Lorraine, ...	125	20,511	164·0	5 = 0·24

Finally, there has been made a last comparison relative to the seriousness of the accidents occurring. To this end, we have compared for the textile industry the accidents followed by temporary incapacity to work with those which have entailed permanent incapacity (death, permanent incapacity or permanent partial incapacity for work united); that is to say, to those which have had permanent and irreparable results.

These are the results to which we arrive:

TABLE III.

COUNTRY.	Accidents having had lasting results.	Accidents which have only brought Temporary Incapacity for Work.	TOTAL.
	per cent.	*per cent.*	
Prussia, ...	479 = 89·0	59 = 11·0	538
Saxony, ...	220 = 92·8	17 = 7·2	237
Bavaria, ...	64 = 88·9	8 = 11·1	72
Wurtemberg, ...	54 = 94·7	3 = 5·3	57
Other countries of Germany, ...	80 = 97·6	2 = 2·4	82
Total, ...	897 = 91·0	89 = 9·0	986
Alsace-Lorraine, ...	95 = 76·0	30 = 24·0	125

We see that in the textile industry for 100 accidents occurring in Alsace, twenty-four have entailed only tem-

porary incapacity for work, while in Germany there have been nine per cent. of accidents not serious. From this point of view, then, the advantage rests with Alsace.

From all these comparisons we have the encouraging results that the efforts of the Association of Mulhouse have borne their fruits and that they have attained by private effort that which the official regulations alone have not been able to realize elsewhere.

A MIRROR GAUGE.

By Joseph Becker.

The following is a description of my mirror gauge; an instrument for measuring the thickness of any glass mirror without unframing it.

My gauge consists of a piece of plate glass (*Figs. 1, 2* and *3*), having on one face a graduation *O 1*, and on the opposite

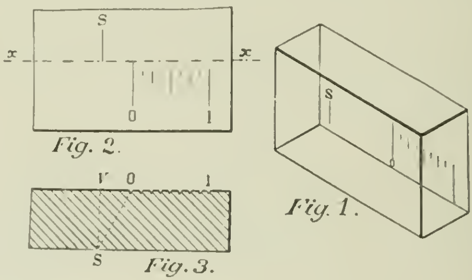

Fig. 2. *Fig. 1.* *Fig. 3.*

face a mark or sight *S*. For reasons to appear further on, the sight *S* is so placed that in the right-angled triangle *S V O* the side *O V* is equal to one-half of the side *V S*.

In use, the gauge is placed (*Fig. 4*) with its graduated face against *B*, the mirror to be measured. Behind the silver backing *C* is formed the virtual image *A'* of the gauge. The observer places his eye so as to catch the ray of light *O S E*; in other words, he places himself so as to see the inner ends of sights *S* and *O* meet and form a line *S O*, the general appearance of the graduations being as indicated in *Fig. 5*.

The observer then reads off the distance $O'\,O$ which is equal to the thickness of the mirror and is, in the case illustrated, five and one-half subdivisions of the scale.

Noting that $O'O$ of *Fig. 5* is simply $O'm'$ of *Fig. 4*, we can formulate the following theory of the instrument.

As both A and B are of glass the line $m'\,N\,O\,S$ is straight, forming similar triangles $m'\,O'\,O$ and $O\,V\,S$. The line $O\,V$

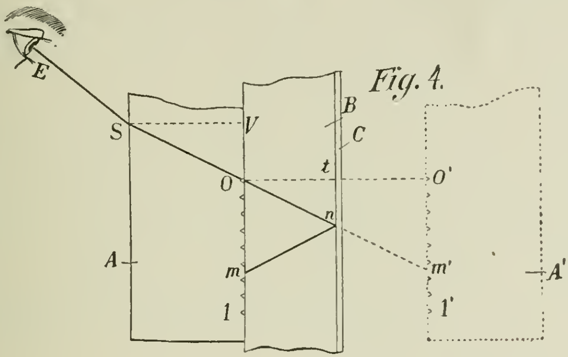

Fig. 4.

we know is half of line $V\,S$, therefore, $m'\,O'$ must be half of line $O'O$, or equal to $O\,t$, the thickness of the mirror.

The general formula giving the thickness x of the mirror is

$$x = O'\,m' \times n\,\frac{S\,V}{2\,V\,O}$$

n being the ratio of the unit of the scale $O\,1$ to the unit of measurement.

Fig. 5.

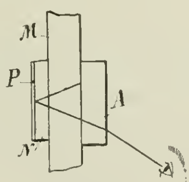

Fig. 6.

The formula reduces itself to the desirable form $x = O'm'$ when the constant factor

$$n\,\frac{S\,V}{2\,V\,O} = 1$$

In the instrument as I prefer to make it, and as I have shown it in *Figs. 1, 2, 3,*

$$n = 1$$

and

$$\frac{S\,V}{2\,V\,O} = 1$$

When different kinds of glass are to be handled, their refractive power may slightly differ from that of the gauge. In this case the readings are subject to a small error due to the bending of the ray $n\,S$ at O (*Fig. 4*).

The gauge can be used for measuring unsilvered plate glass in places where other means of measurement are too troublesome, as will appear in the following method, due to Mr. Samuel Vaughan, of Washington, D. C. In *Fig. 6*, M is the plate to be measured, N is a small piece of looking glass, and P is the gauge which gives the joint thickness of M and N. By subtracting the known thickness of N the thickness of M is found.

WASHINGTON D. C., February 22, 1892.

THE HISTORY AND MODERN DEVELOPMENT OF THE ART OF INTERCHANGEABLE CONSTRUCTION IN MECHANISM.*

BY W. F. DURFEE.

[*Continued from vol. cxxxvi, p. 431.*]

Among all the improvements which have combined to make the lathe, in its various forms, the most important of machine tools, for promoting the art of interchangeable construction, the device known as the slide rest is most conspicuous. Like most important inventions, this has more than one claimant.

It is a commonly expressed opinion by writers that the slide-rest was invented by Sir Samuel Bentham, as it is clearly described in his patent of 1793; and there is no

* A paper read before the Mechanical Section of the Engineering Congress, at the World's Columbian Exposition (August, 1893).

doubt whatever but that Henry Maudsley made a tool of that kind while in the employ of Joseph Bramah, in 1794, which was named by his shopmates "Maudsley's go-cart." Joseph Clement is also deserving of great credit as an improver of the slide-rest, in the early part of the present century; but, it is certain that the evidence relative to the ideas embodied in the slide-rest amply justifies the assignment of its origin to France, not only in virtue of the suggestion contained in Bessoni's work already referred to, but, more particularly in view of the fact that in the great Encyclopædia of Diderot there is an elaborate engraving of a "slide-rest" which, anticipates anything of the kind claimed to have been made in England by at least twenty years.

The first lathe for cutting metallic screws was devised by some French watchmaker,* early in the last century, for cutting the thread on the fusees of watches. This lathe is remarkable for a taper attachment quite similar in its idea and functions to that used in modern tools.

The next step in the direction of the modern screw cutting lathe was made in 1775, by Jesse Ramsden, who constructed a small lathe for cutting the "endless screw" or "worm" of his "dividing engine." This lathe had "change wheels" and a tool holder on a slide moved by a "lead screw."

In the year 1816, Richard Roberts, of Manchester, invented the modern form of screw-cutting lathe, and in 1830, a Mr. Parson, of London, invented the swivelling tool post, and in 1831 was awarded the silver medal of the Society of Arts for his ingenuity. Prior to 1828, Joseph Clement invented a surfacing lathe, in which the speed was automatically reduced and the feed automatically regulated as the tool travelled from the centre to the circumference of the work being faced. This lathe was a "gap lathe;" it had flat surfaces for the top of its bed, conical bearings for its main spindle, whose "end shake" was taken by a pivot set-screw in an oil-tight box, and was provided with a two-speed

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* *Traité de l'Horlogerie mechanique et pratique.* Par Thiout. Paris, 1741. There are several fusee lathes described in this work. These tools were in use several years before the work was published.—W. F. D.

cone pulley, and a slow-speed equivalent to modern "back gear," which could be thrown out at pleasure. It also had a compound "slide-rest."

The invention of the "apron" on the front of the "tool carriage," and the idea of attaching the various feed controlling mechanisms thereto, is believed to have originated with Baxter G. Whitney, of Winchendon, Mass., the well-known inventor of the "gauge lathe," who also devised the first "universal swivelling bearing" for line shafting.

The form of lathe, known as the "turret lathe," which has occupied a very important relation to the manufacture of interchangeable mechanism during the past thirty years, is believed to be of American origin, although no record of any patent can be found, and no one appears to know who designed the first tool of that kind.

So far as ascertained, it seems to have been first made to meet some special emergency and to have been copied with more or less variation from shop to shop, until at last, the Robins & Lawrence Company, of Windsor, Vt., at the request of F. W. Howe, made the first machines that were regularly made for sale. Some of these machines were put at work in the factory of the Savage Firearms Company, about 1860, and one of the first lot made was purchased by the Brown & Sharpe Manufacturing Company, of Providence, R. I., and soon after they commenced to make this tool for the market, and were followed by the Pratt & Whitney Company, of Hartford, Conn. The successors of the Robins & Lawrence Company, the Jones & Lamson Machine Company, of Springfield, Vt., and the other eminent firms named, have doubtless built a large majority of the turret lathes thus far sold. This tool has commended itself to all makers of interchangable mechanism for a large variety of work, and for the special service of manufacturing machine screws, it has been made automatic by Sharpe, of Hartford, Conn., and as its capabilities are carefully studied, its field of usefulness continues to expand.

Lathes for ornamental turning and the decoration of wood, ivory and metal, doubtless originated in France. In Bessoni's work (1578), already referred to, there are two

"swash lathes" shown for turning a variety of intoxicated vases and balusters, which were in that day doubtless regarded as ornamental.

A modification of the lathe which has had a very important influence upon the production of interchangeable work is that known as the "Blanchard lathe." This celebrated tool was patented by Thomas Blanchard, January 20, 1820, and his patent was twice renewed by special act of Congress, for terms of fourteen years, the last renewal being dated January 20, 1848.

If we are to believe all that has been written in commendation of this machine tool, we shall certainly conclude that Blanchard's invention was an original conception and that it is American genius and inventive talent that the world must thank for an idea that conferred upon mechanism, automatic imitative powers, that were wholly unknown before. We have not time to discuss all of the evidence of the erroneous character of this view, but we will note a few of its more conspicuous features. As early as 1772, sixteen years before Blanchard was born, we find in the great French Encyclopædia, an engraving of machinery for turning irregular forms, in which there is a roller operating against a revolving pattern and controlling the movement of the tool in such a way as to produce on the substance being turned a copy of the outlines of the pattern. In Bourgeron's *L'Art de Jeurneus*, published in 1816, we are shown methods of reproducing medallion portraits by automatic machinery, and it is well known that in the latter years of the life of James Watt, he successfully duplicated busts by mechanism of his contriving. In the famous block machinery Brunel, which was put in operation in 1806, a revolving cutter was regulated in its action by a profile plate.

Although the invention of Blanchard was not in its chief elements, entirely original, nevertheless, the combination was sufficiently novel and useful to entitle it to high rank among the more important improvements that have contributed to the perfecting of the art of interchangeable construction.

Grinding machines for the production of flat and cylindri-

cal surfaces by the action of emery or corundum wheels had their origin in America, and have largely augmented the possibility of cheaply producing accurate work in metal. The grinding lathe, as perfected by J. Morton Pool, in 1868, is believed to have been the first apparatus by which long cylindrical rolls could be given automatically and at once, an accurate surface and uniform diameter. So delicate is the action of the very simple mechanism employed that a uniform reduction of diameter of $\frac{1}{200000}$ inch is quite within its powers. The invention and successful operation of this admirable tool has made possible the manufacture of widths of paper unknown and unattainable before.

The success and possibility even of the various grinding lathes and similar machine tools that have been developed in the past twenty years is due to a very simple American invention; the solid emery or corundum wheel, which has ground its way into recognition and universal employment in all the machine shops of the world.

The modification of the lathe, known as the boring machine, probably originated in Germany, for in a work published in Nuremberg, 1662,* there is an engraving of a duplex boring mill, operating upon two musket barrels at the same time, and in a treatise on artillery, published in France in 1647,† there is a vignette, in which a cannon is shown as being bored by a vertical bar.

About the middle of the last century, cannon and pump cylinders, also cylinders for Newcomen engines were bored horizontally in rude boring mills at Carron Iron Works, in Scotland, and in 1769, that celebrated engineer, John Smeaton, designed new boring machinery for these works. It does not appear that this machinery was perfectly satisfactory, as in a proposal from Boulton & Watt to the Carron Iron Company, in 1776, for the construction of an engine *to return the water* to *their water wheels*, Mr. Boulton says: "Mr. Wilkinson has bored us several cylinders almost without error; that of fifty inches diameter, which we have put up at Tip-

* *Theatrum Machinarum novum, et cet.* Per Georgius Andream Bocklerum. 1662.

† *Memoires d'Artillerie.* Par le Sr Surirey de Saint Remy.

ton, does not err the thickness of an old shilling in any part, so you must either improve your method of boring, or we must furnish the cylinder to you." "The thickness of an old shilling" seems to have been regarded as a very satisfactory standard of permissible error in such work 100 years ago. The Mr. Wilkinson spoken of by Mr. Boulton, was John Wilkinson, of Bersham, near Chester, who had invented improvements in boring machinery in 1775. He it was who first moved a cutter head along a boring bar, supported at each end, and as simple as this idea now seems, it was not perceived by such acute men as Smeaton and Boulton and Watt.

The first planing machine of which we have any account is said by Rennie (Buchanan on *Mill Work*), to have been invented by Nicholas Torq, a French clockmaker, in 1751, and to have been actually used in planing the interior of the wrought-iron pump barrels used in the repairs of the machine erected by order of Louis XIV, for the supply of the water works at Versailles.

We are told that the pumps varied in size from 10 inches to 4 feet in diameter, and were from 7 to 10 feet in length, made of wrought-iron staves planed on their edges, before they were assembled and confined with encircling wrought-iron hoops 3 inches wide and ½ inch thick. A pump barrel 10 inches in diameter and 7 feet long was made up of nine staves secured by twelve hoops.

If Rennie's account is correct, M. Torq had a large job for a newly invented machine, of which it is recorded that it did the work in a perfectly satisfactory manner.

I shall not attempt to discuss the question of who was entitled to the credit of first introducing the metal planing machine into England. Claims have been made for Bramah, Fox, Clement, Murray, Roberts and possibly some others. There is little doubt that all the persons named constructed, independent of each other, during the thirty years preceding the year 1820, some form of mechanism for planing metal. The best description we have of any of these early planing machines is of one built by Joseph Clement, in 1825, as an improvement on one constructed by him prior to 1820. In

this machine the bed was 2 feet 8 inches wide and 12 feet long, and was supported upon stationary bearing wheels, 3 feet in diameter and 2 inch face. The bed was moved by two pinions working into two racks on its under side. The planer was driven by a belt 3 inches wide, running upon a pulley 4 feet in diameter. This tool was said to be a practical success, and at the rate of eighteen shillings per square foot of surface planed earned for its owner £10 for each day it was employed.

This machine was no mere experiment, as it is known to have been in regular use in 1863, thirty-eight years after its construction, and nineteen years after the death of its inventor. Another interesting type of planer was built by Benjamin Hicks, of Bolton, about the year 1840.

This was a "pit planer;" the piece operated upon being stationary, and the crosshead and tool moved by two steel belts 3 inches wide, running on pulleys 3 feet in diameter. This planer could plane a piece of work 30 feet long and 9 feet 6 inches wide.

The style of planer, known as the "shaping machine," was invented by the late James Nasmyth (the inventor of the steam hammer) in 1836, it was at first called "Nasmyth's steam arm." It has been greatly improved by Whitworth and other leading tool builders.

The first machine for planing the teeth of wheels in which the action of the tool was regulated by a guide curve, was invented in 1839, by the brothers Glovet.

The vertical planer, or "slotting machine," was doubtless suggested by the mortising machine for wood. Machines of this kind were built by Nasmyth in 1836. America had done its full share in the development and improvement of construction of machine tools of all kinds, and the work of Wm. Sellers & Co., Bement, Miles & Co., Brown & Sharpe, Pratt & Whitney Company, the Putnam Machine Company, Niles Tool Works, and scores of other makers of American machinery is known and honored wherever hammers beat and wheels turn.

The art of wire drawing has been a liberal contributor to the development of the art of interchangeable construc-

tion. The making of wire was originally accomplished by beating the metal into thin strips, then shearing it into strands of a more or less square cross-section, and then hammering these strands until their angles disappeared, and the strands became approximately round.

Until early in the fourteenth century this had been the only method of making wire from remote antiquity, and was probably practised in Egypt in the time of Moses (1450 B. C.) for we are are told in Exodus 39 : 3, that "they did beat the gold into thin plates, and cut it into wires, to work it in the blue, and in the purple, and in the scarlet, and in the fine linen, with cunning work."

This rude method was improved in Germany by the invention of the draw-plate, which was in use in Augsburg as early as 1350. So long as the rounding was accomplished by the hammer, the workmen were called "wire smiths;" but after the invention of drawing they were named "wire drawers" or "wire millers." So slow did improvement travel in the Middle Ages, that wire drawing was not introduced into England until about 200 years after its invention in Germany.

In order to protect and stimulate the manufacture of wire in England, His Majesty King Charles I, in the sixth year of his reign (1631), *absolutely prohibited* the importation of foreign iron wire, and of cards made from the same. This prohibitory act accomplished its intended purpose so well, that eight years thereafter the King prohibited the importation of brass wire. There is abundant evidence that England's infant industries were carefully nurtured by adequate legal protection.

The relation of wire to interchangeable mechanism is very close. The manufacture of pins, needles, wire nails, wood screws, and fish hooks, rests solidly upon a substratum of manufactured wire. English chronicles tell us that the making of "Spanish needles," as the fine sewing needles were formerly designated, was first taught in England by Elias Crowse, a German about the eighth year of Queen Elizabeth; and in Queen Mary's time there was a negro made fine "Spanish needles" in Cheapside, "but would never teach his art to any."

The first stage in the making of the assembling screws of all classes of small machinery, is the making of wire.

Wires have been produced by a combination of mechanical and chemical operations, of a fineness of $\frac{1}{50000}$ inch, and so smooth and uniform as to rival the spider's web for use in micrometers and similar instruments. The process of wire drawing is not confined to products of a circular cross-section, and a great variety of shapes have been made, but the most interesting form is doubtless that known as "pinion wire," from which the pinions and arbors used in watches, were for many years made. Pinion wire was also used in the beginning of the century in the construction of clocks. The preparation of wheels and pinions for clockmakers' use seems to have been at that time a distinct industry; for in Ree's Encyclopædia (1819) we are told that, "Iron-mongers and tool sellers having on sale sets of wheels and arbors with pinions of different numbers ready slit, and also pinion steel wire drawn in proper shape for the teeth of small pinions, of which all clockmakers usually avail themselves, instead of preparing them." Thus early does the interchangeability of the parts of clocks manifest itself.

Another application of the principle of wire drawing was originally introduced in the British Mint by Sir John Barton, for equalizing the thickness of the fillets of gold and silver from which the blanks for the coin were cut. This consists in drawing the "fillet" (after it has been nearly reduced to the proper thickness by rolls) between stationary hardened steel cylinders, one of which is adjustable by mechanism which enables $\frac{1}{100000}$ inch to be readily appreciated.

The art of drawing tubes of metal through fixed dies is a natural outgrowth of the art of wire drawing, and a further development of this art is exemplified by the manufacture of metallic cartridges, in which we have an admirable illustration of one of the most recent and most important developments of the art of interchangeable construction.

The art of making a cartridge shell of sheet metal originated in France. In the year 1824, M. Cazalet patented

a cartridge of this material, and in 1834, M. Roberts, of Paris, invented a metallic cartridge, in which the fulminate was deposited in an anulus around its base, which was made of a separate piece of metal from the body of the cartridge. The idea of using a metallic cartridge did not attract much attention, until M. Flobert, about 1850, commenced the manufacture of a pistol intended for use for practice at short range. This pistol could only use a small metallic cartridge, charged exclusively with fulminate. Flobert's pistol and ammunition met with considerable favor for its purpose, and doubtless it had a stimulating influence upon the development of the manufacture of metallic cartridges of an improved type.

To Smith & Wesson, of Springfield, Mass., without doubt belongs the credit of making the first metallic cartridge suited to the requirements of actual service in war. In 1854, they patented a form of cartridge that has always been used in the well-known pistol made by this firm.

Since the above date, the idea has been adapted to breech-loading muskets of a large variety of styles, and at the present time, metallic cartridges are made for quick-firing guns of 3-inch calibre.

It is believed that the general system adopted in the manufacture of the modern metallic cartridge is purely American.

The rapidity, accuracy and economy with which they are manufactured, is the result of the perfecting of a large number of special automatic machines, whose work is so exact that any cartridge will fit accurately: that is, will never be too large for, and never more than $\frac{1}{1000}$ inch smaller than, the chamber of the arm in which it is intended to be fired.

The Union Metallic Cartridge Company, of Bridgeport, Conn., which for thirty years was under the skilful management of the late A. C. Hobbs, has been the leader in the development of this industry, and have supplied the principal foreign governments with large quantities of ammunition and cartridge-making machinery, and it is only just to say that the system of manufacturing metallic cartridges,

now regarded as the best throughout the world was brought to its present state of perfection in these works, during their administration by Mr. Hobbs.

The art of cold punching of sheet metal has important collateral relations to the art of interchangeable construction. Perhaps the best exemplifications of the art of punching is furnished by the gold and silver blanks which are punched in the several mints of the world for subsequent coining into money. The weight of these blanks must be uniform for the specific coin for which they are intended, and this can only be insured by extraordinary care in the making of the punches and dies. The flat links of the chains used in the old fusee watches were punched as early as the middle of the last century.

The punch was made of the same contour as the link, and was guided in its work by two conical pins, projecting from its face; these pins entered the holes intended for the rivets which had previously been punched in the sheet steel, from which the links were to be made. The metal was thus guided to its proper position on the die, so that when the punch took effect, the exterior of the resulting link was symmetrical with regard to the rivet holes through it. This principle thus early discovered is of frequent application in all similar operations. The art of punching has, in comparatively recent times, had coupled with it the art of shaping the metal blank into its various forms, immediately after the punching operation is completed; boxes and their covers, "percussion caps," the cups "for metallic cartridges" and the metal bases of "shot shells" are made in this way.

[*To be concluded.*]

The Chemical Section

OF THE

Franklin Institute.

[*Proceedings of the stated meeting held Tuesday, December 19, 1893.*]

Hall of the Franklin Institute,
Philadelphia, December 19, 1893.

Dr. Wm. H. Greene, President, in the chair.

Mr. Boyer proposed for membership the name of Dr. Nelson B. Mayer, 945 North Eighth Street, Philadelphia; the name was referred to the Committee on Admissions.

The Secretary read his annual report which was accepted. The Treasurer also made his annual report, showing cash on hand at the beginning of the year $74.16; receipts during the year, $141; expenditures, $187.64; leaving a balance of $27.52 in the treasury. The Finance Committee audited the Treasurer's account and found it correct.

The Conservator reported that he had on hand a number of volumes of the proceedings of the Section, which, following instructions from the Section, he would dispose of in accordance with his judgment of the best interests of the Section.

Owing to the fact that Prof. E. F. Smith had declined the nomination for President of the Section, on motion it was voted that nominations for President be re-opened.

Dr. D. K. Tuttle and Dr. H. F. Keller were then nominated; the latter gentleman, however, declined, thus leaving Dr. Tuttle the only nominee, when it was voted that nominations be closed. The Secretary was directed to cast the vote of the Section for the following candidates, who were thereupon declared elected to their respective offices:

President, ...	Dr. D. K. Tuttle.
Vice-Presidents, ...	Mr. H Pemberton, Jr. Dr. L. B. Hall.
Secretary, ...	Dr. Wm. C. Day.
Treasurer, ...	Dr. H. W. Jayne.
Conservator, ...	Dr. Wm. H. Wahl.

The Secretary was then instructed to cast the ballot of the Section for Dr. S. C. Hooker, Mr. Reuben Haines, and Mr. C. S. Boyer, as members of the Committee on Admissions, to act with the President, Secretary, Treasurer and Conservator as the remaining four members; the candidates were declared elected.

On motion, it was voted that the Secretary notify the Institute to renew the yearly subscriptions to the current journals subscribed for during 1893.

Dr. W. J. Williams submitted for publication a paper embodying the results of his examination of Pemberton's method of phosphoric acid determination. The main points of this paper had already been brought before the Section at the November meeting by Dr. Terne, who read at that time a communication from Dr. Williams. The paper was referred for publication.

Dr. Bruno Terne then read a paper, entitled "Contribution to Pemberton's Volumetric Method for Phosphoric Acid Determination." This paper was the joint production of Dr. Terne and Mr. Francis Bergami.

Mr. Bergami then followed with a contribution, entitled "Comparison of Pemberton's Method of Phosphoric Acid Determination with the Official Method."

Both papers evoked interesting discussion and comment from many of the members present.

Mr. Reuben Haines was prevented by illness from being present to read the two papers from him announced on the program of the meeting. One of them was presented, namely, "Normal Chlorine in Spring Water near Philadelphia." Owing to the lateness of the hour this paper was read by title and referred for publication. The meeting then adjourned.

WM. C. DAY, *Secretary.*

ROBERT A. FISHER.

Robert Andrews Fisher, a member of the Philadelphia family of that name, died quite suddenly on October 6, 1893. He was the son of Jabez M. Fisher and Nancy Andrews, his wife; having been born on December 21, 1832. Miers Fisher, his grandfather, was a distinguished Quaker lawyer of Revolutionary times.

Mr. Fisher was, in the early fifties, the assistant to Prof. John A. Porter, of Yale College, and, at one time, was Professor of Chemistry at Brown University, which conferred upon him an honorary degree. In those days no facilities were offered in this country, to chemists who were desirous of pursuing advanced courses in their science. He, accordingly, went to Europe, studying at Göttingen and at Heidelberg, and, later on, attending lectures in Paris. Upon his return to America, he accepted the chair of chemistry and mineralogy in the University of California, devoting considerable attention, also, to the mining industry then just

developing in the far West. In this direction, in connection with Prof. Samuel W. Johnson, now of New Haven, Conn., his services, as mining expert, were called upon by the Directors of the Richmond mine in Nevada.

During the last fifteen years of his life he was the consulting chemist to several large industrial works in Philadelphia, having been associated with the Pennsylvania Salt Manufacturing Company, in this capacity, during the greater part of this time. The President of this company bears the following testimony to his professional ability:

"Professor Fisher had achieved a high position in his chosen profession of chemistry, having given especial attention to the scientific branch of the art of paper-making, and was considered an authority on all technical and practical questions arising in that particular manufacture. His knowledge, however, was general, and extended largely into the chemical composition of food products and manufactures, and, in this direction, his attainments and clear, concise conclusions rendered his opinions much sought after on all mooted points."

He also devoted much attention to the manufacture of sulphate of alumina from beauxite as well as from other materials, and the number of patents taken out by him bears evidence to his ingenuity and industry. He took an active part, moreover, in the introduction of the sulphite process of paper-making, in the Western States.

Mr. Fisher was a member of the Chemical Section of the Franklin Institute, and also of the American Chemical Society. He was well informed on all the recent advances in his science, particularly in such as relate to the application of chemistry to the industrial arts, and while possessing a keen insight into the important points of many scientific questions, was careful and conservative in his judgment.

Personally, Mr. Fisher was most considerate and courteous in his bearing. He was widely connected in Philadelphia, and endeared himself to many friends. P.

NOTES ON THE EXAMINATION OF BEESWAX.

By Lyman F. Kebler.

[*Read at the stated meeting of the Chemical Section, held Nov. 21, 1893.*]

When the contribution,* entitled "An Examination of Beeswax," by E. G. Parry and P. A. Estcourt, appeared, describing the sophistication of this article in the English market, the writer had nearly completed a communication on the same subject with reference to this country.

The waxes examined, and the results submitted below, were samples sent to this laboratory for the past year from various parts of the country as specimens representing the waxes the dealers had in stock, and it is not more than fair to suppose that the samples submitted for examination were equal, if not superior, to the beeswax in our market.

At first the process of the legally recognized authority was used. After some time a sample which had been rejected was investigated and reported as complying *in toto* with the requirements of the above authority. The writer was ignorant of the rejection of the wax until he had made his report. The wax had been rejected because it was unfit for electrotyping, and must therefore contain an adulterant of some kind, probably "grease" or some fatty substance. The wax was again looked into with the same results. It has since been found by experiment that the impurity could have been detected by using a twenty per cent. solution of sodium hydroxide in place of a fifteen per cent. solution.

The wax was now examined rigidly by the best methods.

In view of the fact that the literature on wax analysis is at best fragmentary and the methods imperfect, and that the object of this contribution is not only to present the condition of wax in our market, but also to make the paper of practical value to analysts, it is desirable to give here a

* Read before the Brit. Pharm. Conference, Nottingham, through the *Am. Drug. and Pharm. Record*, **23**, 158.

résumé of the best methods employed and the references in the literature.

First, let us consider briefly the composition of beeswax. It is a mixture of *myricin*, *cerin* and *cerolein*.

Myricin ($C_{46}H_{92}O_2$), forms the chief constituent of wax. It is insoluble in alcohol and fuses at 64° C.

Cerolein constitutes only from four to five per cent. of the wax, has an acid reaction, and is the constituent to which wax owes its tenacity, odor and color.

Cerotic acid, or cerin ($C_{27}H_{54}O_2$), is not a constant constituent of beeswax.

B. C. Brodie,* in his classic *Untersuchung über die chemische Natur des Wachses*, has shown that cerin consists essentially of a high fatty acid, *i. e.*, cerotic acid, while myricin is the palmetic ether of melissic alcohol. F. Schwalb† and F. Nafzger‡ have shown that wax contains small quantities of acids related to cerotic acid, as melissic acid; also some non-saturated acids of the oleic acid series and some alcohols related to cerylic alcohol, as melissic alcohol. They have also proven it to contain saturated hydrocarbons, such as hentriacontane ($C_{31}H_{64}$) and hyptacosane ($C_{27}H_{50}$).

It was thirty-four years after the composition of beeswax was made known, or the way paved for the introduction of a method, before one was proposed for the examination of this article based on the determination of the free and combined acids, respectively.

The Acid and the Ether Numbers.—These were determined by the well-known method of Hübl§ (not the iodine number), who was the first to apply the method in a practical way. The method is sometimes awarded to Hehner, who translated his results into cerotic acid and palmate of myricle. Hehner‖ applied the method a few months before Hübl

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* 1848, *Ann. Chem.* (Liebig), **67**, 180; *Phil. Trans.*, London, **136**, 147. 1849, *Ann. Chem.* (Liebig), **71**, 144.

† 1884, *Ann. Chem.* (Liebig), **224**, 225.

‡ 1886, *Ibid.*, **235**, 106.

§ 1883, *Dingl. poly. J.*, **249**, 338.

‖ 1883, *Analyst*, **8**, 16.

did, but Becker* was the first to apply the principle of Köttstorfer† to the analysis of beeswax. Hübl's method is recognized as the most elegant, most convenient, as well as the best method for establishing the purity of this article. The method ‡ in detail is: heat three or four grams of the wax with twenty cubic centimetres of neutral ninety-five per cent. alcohol, titrate while hot with a semi-normal alcohol solution of potassium hydroxide and phenolphthalein to estimate the acid number; now add twenty cubic centimetres more of the alkaline solution and saponify by boiling the solution briskly with a reflex condenser for one hour, to insure complete saponification. The excess of alkali is then titrated back with semi-normal hydrochloric acid. The number of milligrams of potassium hydroxide required to saturate the free acids of *one gram* of wax is called the "acid number;" that required to decompose the wax ethers, the "ether number."

The acid number varies from nineteen to twenty-one milligrams, the ether number from seventy-three to seventy-six, while their ratio is from 1 : 3·5 to 1 : 3·8. For complete saponification from ninety-two to ninety-seven milligrams of potassium hydroxide are required. After having secured the acid and the ether numbers the quantity of cerotic acid or its equivalent and myricin are easily calculated. Extreme care must be taken in the titration on account of the extraordinarily high molecular weights of both cerotic acid (410) and myricin (676). One cubic centimetre of normal alkali represents 410 milligrams of cerotic acid and 676 milligrams of myricin, respectively.

Determination of the Alcohols.— Unquestionably the alcohols of beeswax belong to the same series, consequently they possess the same chemical properties. Dumas and Stas described an important reaction of the fatty alcohols, viz: the reaction which they give when heated to a moderate temperature with potassium hydroxide. These alcohols

* 1880, *Corr. Bl. Ver. anal Chem.*, **2**, 57; Abst., *Zeit. anal. Chem.*, **19**, 241.

† 1879, *Zeit. anal. Chem.*, **18**, 199 and 431; *Analyst*, **4**, 106.

‡ 1892, H. Röttger, *Chem. Ztg.*, **16**, 1837; *J. Chem. Soc.*, **64**, 351. G. Buchner, *Ibid.*, **16**, 1922; *J. Chem. Soc.*, **64**, 351.

when so treated are converted into the corresponding acid or alkaline salt, and hydrogen is simultaneously disengaged. For example, when melissylic alcohol is distilled with potassium hydroxide the alcohol is decomposed, hydrogen being evolved on the one hand, and potassium melissate formed on the other, recalling a more familiar example where potassium acetate is formed by treating ordinary alcohol in a similar manner. The constituents of wax (not alcohol), are not affected by this treatment, consequently by measuring the volume of hydrogen evolved, from a given weight, the proportion of alcohols can be approximately estimated. C. Hell,* H. Strürcke † and F. Schwalb ‡ applied the above reaction to beeswax long before MM. A. and P. Busine,§ but it was these last two investigators who simplified the apparatus and studied the conditions of success. They proceed as follows: melt two to ten grams of the wax in a porcelain dish, mix with an equal weight of pulverized caustic potash, mix the mass again with three or four times its weight of pulverized caustic potash, then introduce the mixture into a flask and heat on a mercury bath to 250° C. for two hours. The reaction begins at 180° C. The volume of hydrogen evolved by one gram of the wax, varies from 53·5 to 57·5 cubic centimetres at 0° C., and 760 millimetres pressure, corresponding to a percentage of melissic alcohol varying from 52·5 to 56·5.

Determination of Hydrocarbons.—The hydrocarbons are determined very readily by treating the residuum of the preceding determination with an appropriate solvent, as ether. In the above residue all the acids of the wax and the alcohols have been transformed into a state of alkaline salts, while the hydrocarbons alone remain intact. Hydrocarbons are found in wax in almost constant quantity, varying from 12·72 to 13·78 per cent.

The writer did not execute the last two operations because the apparatus of M. Dupre was not available.

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* 1884, *Ann. Chem.* (Liebig), **223**, 269; *Chem. Ztg.*, **8**, 859.

† 1884, *Ibid.*, **223**, 295; *Chem. Ztg.*, **8**, 860.

‡ 1886, *Ibid.*, **235**, 106.

§ 1890, *Bull. Soc. Chim.* (3), **3**, 567; *Chem. Ztg. Reper.*, **14**, 225.

The Iodine Number.—By treating wax with iodine a new number is obtained which is of considerable value for analytical purposes. This number was determined by the conventional method of Hübl.* The iodine absorbed by the wax being small it was necessary to use a larger quantity of the substance than ordinarily, consequently more chloroform was needed. The method † in detail is: dissolve two grams of the wax in forty cubic centimetres of chloroform in a glass stoppered flask. Add twenty-five cubic centimetres of an iodine solution, containing twenty-five grams of iodine and thirty grams of mercuric chloride dissolved in ninety-five per cent. alcohol and made up to one litre, and shake. Place the flask into a dark closet for three hours, then add fifteen cubic centimetres of a ten per cent. solution of potassium iodide and 100 cubic centimetres of water, finally titrate the free iodine with a standardized solution of sodium thiosulphate. The "iodine number" expresses the per cent. of iodine absorbed by the wax. It is quite essential to carry blank experiments in order to secure reliable results.

The Melting Point.—This is determined as follows: dip the bulb of the thermometer into the sample of melted wax, for an instant. On cooling, the bulb is covered with a film of the wax. Introduce the thermometer into a wide mouth bottle through its perforated cork. The bottle is now hung into a beaker containing water at about 65° C., carefully noting the temperature at the instant a hanging drop is formed; this is taken as the melting point. Other ‡ methods were used but the above method gave concordant results without consuming too much time.

Specific Gravity.§—This was obtained by diluting alcohol so that the wax, previously melted and cooled normally,

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* 1884, *Dingl. poly. J.*, **253**, 281; *J. Chem. Soc.*, **46**, 1435; *Am. Chem. J.*, **6**, 285; *J. Soc. Chem. Ind.*, **3**, 641.

† *U. S. Bull.*, No. **13**, 818.

‡ 1883, Guichard, *Proc. Royal Soc. Ed.*, **106**, 432, 532; *Zeit. anal. Chem.*, **22**, 70. 1884, H. Krüss, *Zeit. f. Instrumentenkunde*, **4**, 32. 1886, C. Reinhardt, *Zeit. anal. Chem.*, **25**, 11. 1887, H. W. Wiley, *J. anal. Chem.*, **1**, 39.

§ 1879, Hager, *Analyst*, **4**, 206.

would float indifferently in it. The specific gravity of the alcohol being identical with that of the floating wax, it is necessary only to secure the specific gravity of the liquid with a picnometer, or a specific gravity spindle, and we have the specific gravity of the wax. The most trustworthy methods employed for securing the specific gravity of fats, waxes, etc., are given in the *U. S. Bull.*, No. **13**, 40–43.

Stearin, Stearic Acid, etc.—Any foreign acid can easily be detected by Hübl's method. Fehling's* method gives an unmistakable turbidity with *one per cent.* of stearic acid, and is executed thus: boil one gram of the wax in a test tube with ten cubic centimetres of eighty per cent. alcohol for a few minutes, allow to cool to 18° or 20° C., filter, to the filtrate add water and shake. If stearic acid is present it separates in flocks on the surface, leaving the underlying fluid nearly clear.

A. H. Allen† gives a method depending on the insolubility of lead stearate in alcohol. Proceed thus: boil the wax for forty minutes with twenty parts of alcohol, cool; the cerolein and some of the stearic acid remain in solution. Filter and treat the filtrate with an alcoholic solution of lead acetate. If a flocculent precipitate of lead stearate is formed, stearic acid is contained in the wax.

F. Jean's‡ method was also tried but proved unreliable, at all events waxes proven to be free from stearic acid by Hübl's and Fehling's methods gave unmistakable evidence of stearic acid.

7·8 centimetres of semi-normal alkali equals one gram of commercial stearic acid.

Stearin may be detected by the methods employed for stearic acid.

Rosin.—E. Donath's§ method, modified by E. Schmidt,‖ was applied in each case, and is executed thus: place five grams of the wax into a flask, add twenty cubic centimetres

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* 1858, *Dingl. poly. J.*, **147**, 222; see, also, *Chem. Ztg.*, 1890, **14**, 606.

† *Commercial Organic Analysis*, **2**, 213.

‡ 1891, *Bull. Soc. Chem.* (3), **5**, 3.

§ 1873, *Dingl. poly. J.*, **205**, 131; abst. *Zeit. anal. Chem.*, **12**, 325.

‖ 1877, *Ber.*, **10**, 131, 837; *Zeit. anal. Chem.*, **17**, 509.

of crude nitric acid (specific gravity 1·32), heat the mixture to boiling and keep at this temperature for one minute. Add an equal bulk of cold water, then an excess of ammonia water. With pure wax the alkaline fluid is colored yellow only, but in presence of rosin a deep brown.

Paraffin.—Paraffin is a common adulterant of beeswax. In fact, some samples of wax might more appropriately be reported as adulterated paraffin, for as high as eighty per cent. of this substance has been found mixed with wax in our markets.

There are many methods* for detecting paraffin and its allies, but the process of the United States Pharmacopœia has given the writer results as reliable as any, and is outlined thus: "if five grams of yellow wax be heated in a flask for fifteen minutes with twenty-five cubic centimetres of sulphuric acid to 160° C., and the mixture diluted with water, no wax-like body should separate."

Care, however, must be exercised in applying the test, as has been shown by C. C. Sherrard† and C. M. Morse.‡

The paraffin is estimated by decomposing a portion of the wax with concentrated boiling sulphuric acid, the charred mass cooled, washed with water, dried and extracted with a Soxhlet's apparatus by means of ether. The paraffin hydrocarbons are thus obtained in a fairly pure state.

Japan Wax.—E. Buri§ regards this wax as a mixture of glycerides and not as a dipalmatin.

A number of methods are claimed by their various authors to be efficient in detecting this adulterant in beeswax, but none has proven itself very effective in the writer's hands. The borax‖ and sodium carbonate¶ methods only deserve mention. Experience has shown that it would be better to abandon the borax method also, or at least to be

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* See references *U. S. Bull.*, No. **13**, 828; and *Chem. Ztg.*, 1890, **14**, 607.

† 1892. *Proc. Am. Pharm. Assoc.*, **40**, 252.

‡ 1888, Thesis, College Pharm., Mass.

§ 1879, *Arch. d. Pharm.* (3), **14**, 403.

‖ Hager, 1862, *Pharm. Centrhalle*, **3**, 207; 1880, *Dingl. poly. J.*, **238**, 356.

¶ Donath, 1872, *Dingl. poly. J.*, **205**, 137; *Allen's Com. Org. Anal.*, **2**, 212.

extremely cautious in judging from its results, for the separation into layers takes place easier on paper than in the test tube.

Donath's* general reaction for rosin, tallow, stearic acid and vegetable wax gives a valuable indication but is not specific enough. He directs to boil one or two grams of the wax with six or eight cubic centimetres of a concentrated solution (1 to 6) of sodium carbonate for one minute; if an emulsion ensues, which is persistent after the liquid has cooled, the wax. contains one or more of the above adulterants.

Soap.—This adulterant can easily be detected by boiling a small piece of the wax a few minutes with water, cooling, filtering and treating the filtrate with hydrochloric acid. A precipitate indicates the presence of a soap.

Mineral Matters.—Such substances as *kaolin*, *gypsum*, *heavy spar*, *yellow ochre*, *etc.*, are said to be frequently used as adulterants for beeswax, but examinations of late show that the day of such gross sophistication is nearly past. At the present time, adulteration has in many cases become a science.

Starches.—The various starches can easily be detected with the aid of a microscope or by boiling a small piece of the beeswax with a little water, cooling, filtering and to the filtrate adding a few drops of a test solution of iodine. A blue coloration indicates starch.

Above is given a table embodying the results of the analysis of *sixteen* samples of the wax as received, of which *eight* were pure and *eight* adulterated.

Wax No. 1 is placed at the head as a standard, because it is of known purity and is not to be included in the other sixteen samples.

Neither No. 3 nor No. 9 contained any detectable adulterant, yet the ether number is low. Several trials were made, in both cases, to obtain if possible a higher ether number, but without success. Each sample was boiled for

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* Donath, 1872, *Dingl. poly. J.*, **205**, 137; *Allen's Com. Org. Anal.*, **2**, 212.

two hours, so that saponification should have been complete; yet the difficulty might lie here, for R. Benedikt and

Serial Number.	Melting Point.	Specific Gravity at 15° C.	Acid Number.	Ether Number.	Total.	Ratio.	Cerotic Acid.	Myricin.	Total.	Ratio.	Iodine Number.	Adulterants.	Description.
1	64·41	·9600	20·30	74·20	94·50	3·650	14·86	89·57	104·43	6·028	8·35	—	Pure Yellow Wax.
2	62·81	·9608	29·40	70·00	99·40	2·410	21·52	84·50	106·02	3·92	9·31	Stearic Acid.	" "
3	63·20	·9602	18·20	65·80	84·00	3·614	13·32	89·57	102·89	6·731	8·50	—	" "
4	63·80	·9624	20·30	77·00	97·30	3·788	14·86	92·95	107·81	6·547	8·71	—	" "
5	54·42	·9120	14·70	45·59	60·29	3·101	10·76	45·63	56·39	4·240	5·63	Paraffin.	" "
6	62·81	·9641	19·60	75·60	95·20	3·857	14·35	91·26	105·61	6·352	7·26	—	" "
7	63·43	·9630	20·10	74·20	94·30	3·681	14·85	89·5[illegible]	104·42	6·028	6·80	—	Pure Bleached Wax.
8	64·44	·9710	20·30	77·00	97·30	3·788	14·86	92·95	107·81	6·193	6·30	—	" "
9	62·22	·9690	19·60	65·80	85·40	3·357	13·35	76·93	90·28	5·755	9·80	—	" "
10	60·00	·9420	26·20	59·50	85·70	2·260	18·45	71·82	90·27	3·892	11·10	Paraffin, Stearic Acid.	Pure Yellow Wax.
11	63·00	·9620	18·04	74·49	92·53	4·132	13·16	89·95	103·11	6·821	8·70	—	" "
12	63·10	·9581	29·40	71·40	100·80	2·430	21·52	86·19	108·71	4·00	9·66	Stearic Acid.	" "
13	59·00	·9431	17·50	71·35	88·85	4·010	12·81	87·03	99·84	6·890	7·00	Paraffin.	" "
14	64·41	·9581	17·50	67·20	84·70	3·842	12·81	81·12	93·93	6·254	13·10	Paraffin, Rosin.	Manufacturing Wax.
15	62·45	·9500	18·91	71·51	90·42	3·776	13·83	86·33	100·16	6·232	9·11	Paraffin.	Pure Unbleached Wax.
16	63·76	·9520	20·30	74·20	94·50	3·655	14·86	89·57	104·43	6·027	7·42	—	" "
17	62·81	·9690	21·70	81·90	103·61	3·772	15·89	98·86	114·75	6·221	4·31	Probably Japan Wax.	Pure Bleached Wax.

K. Mangold* say that this method is attended with the disadvantage of saponifying some kinds of wax with diffi-

* 1891, *Chem. Ztg.*, 15, 474.

culty. These investigators base their results on what they call "*aufgeschlossenes Wachs.*"

In view of the facts that some wax saponifies with difficulty, that no adulterant was found and that the remaining data were approximately normal, these waxes claim a position among the unadulterated.

Samples Nos. 2 and 12 contain stearic acid or an equivalent, yet the specific gravity and the melting point conform in each case as nearly to those of pure wax as could be required. How the manufacturer succeeded in doing this is a question for us to solve.

Heintz* has shown that by mixing stearic and palmetic acids in different proportions a melting point, varying from 69°·2 C. to 55°·1 C., can be secured. Was it a mixture of this kind? The writer was unable to decide.

The use of stearic acid, as an adulterant for beeswax, must be of comparatively recent date, for Hassel, who generally enumerates every conceivable adulterant, in his admirable work, does not allude to it, and Allen, in his *Commercial Organic Analysis*, **2**, 213, says it is "less frequently employed than some of the other adulterants."

The above results show, and other recent investigations corroborate it, that stearic acid is employed almost as extensively as any other adulterant.

Rosin was found only in the sample, designated "manufacturing wax."

Indications point to the presence of Japan wax in No. 17, but nothing definite could be ascertained, owing to the present inefficient methods at our disposal.

Below is a table embodying the properties of the various substances employed in adulterating beeswax. A few of the data are those of the writer, but the majority were secured from various sources in literature.†

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* *Ann. der Physik.*, **92**, 588; Dragendorff's *Plant Analysis*, 1884, Eng. ed., p. 15.

† 1882, Dieterich, *Arch. der Pharm.* (3), **20**, 454. 1885, O. Dammer, *Illustriertes Lexicon der Verfälschungen*, etc. 1891, A. and P. Busine, *Bull. Soc. Chim.* (3), **5**, 654. R. Benedikt, *Analyse der Fette und Wachsarten, Zweite Auf.*, 311, *et seq.*

Substance.	Melting Point.	15° C. Specific Gravity.	Acids Soluble in Water.	Acid Number.	Ether Number.	Total.	Iodine fixed by 1 Gram of Wax.	Volume of Hydrogen at 0° C. and 760 mm. pressure given per gram.	Hydrocarbons from 1 Gram of Wax.
Yellow beeswax,	62–64	·961– ·964	0·1	19–21	73–76	91–97	8–11	53–57·5	12·5–14·5
Beeswax bleached by various agents,	63–64	·960– ·973	0–2	19–23	74–84·29	93–107·7	1·08–11·36	51–57	11–14 30
Cacao butter,	30–33	·945– ·982	0	0–3	192–200	192–204	34	—	—
Carnaüba wax,	83-84	·999	0	4–6	75–76	79–82	7–9	73–76	1·6
China wax,	53·5	·970	2	22	196	218	6·85	72·3	0
Japan wax,	47–54	·975	2	18–28	194–198	216–222	6– 7·55	69–71	0
Mineral wax,	60–80	·918– ·952	0	0	0	0	0– 0·6	0	100
Paraffin,	38–74	·913– ·914	0	0	0	0	17–31	0	100
Resin,	53·5	1·104–1·108	0	168	10	178	135·6	35	0
Spermaceti,	40–50	·945– ·96	0	0–2	136–142	136–144	—	—	—
Stearic acid,	53·5–69·2	·901–1·00	0	204	5	209	2–4	0	0
Suint wax,	62–66	—	0	95–115	4–7	102–119	13–18·5	0	14–18
Tallow,	42–50·5	·952– ·96	0	2·75–5	19·–208	196–213	27–40	52–60	0
Vegetable wax,	47–55·6	·947	2	17–19	200–210	218–220	6·6–8·2	73–74	0

GENERAL CONCLUSIONS.

Beeswax, in our markets, is adulterated to the extent of fifty per cent. while in the English markets the amount of adulteration rises to sixty-six and two-thirds per cent.

The melting point of beeswax varies from 62° to 64° C. It is raised by adding carnaüba wax, stearic acid, certain mineral waxes and paraffins. China wax, Japan wax, cacao butter, resin, tallow, spermaceti, vegetable wax, certain stearic acids and paraffins, lower it, while it is apparently unaltered when adulterated with suint wax, certain mineral waxes, paraffins and stearic acid.

Beeswax varies in specific gravity from ·960 to ·973 and appears to be greatly influenced only by resin, carnaüba wax and certain mineral waxes, which increase it, and by paraffin, which lowers it.

The "acid number" ranges from nineteen to twenty-one milligrams of potash per gram of beeswax. Stearic acid, resin and suint wax increase, while carnaüba wax, mineral wax, cacao butter, paraffin and spermaceti decrease the acid number. China wax, Japan wax and vegetable wax do not vitiate the number seriously.

The "ether numbers" varying from seventy-three to

seventy-six milligrams of potash per gram of beeswax, are unaffected by adding carnaüba wax; but China wax, Japan wax, cacao butter, tallow, vegetable wax increase it. Mineral wax, paraffin, resin, stearic acid and suint wax decrease it. It must be noted that wax bleached by certain chemical agents may have an ether number as high as eighty-four and yet be pure.

The percentage of iodine varies from eight to eleven, yet wax bleached by certain agents, as chlorine, may vary far from these percentages. Paraffin, mineral waxes and stearic acid lower the percentage, but cacao butter, resin, suint wax and tallow increase it. China wax, carnaüba wax, Japan wax and vegetable wax pass the prescribed limits but very little.

The volume (53· to 57·5 cubic centimetres) of hydrogen evolved from one gram of beeswax and the percentage (12·5 to 14·5) of hydrocarbons evidently are the most reliable data securable; the former being vitiated by all adulterants except tallow, and the latter by all except suint wax.

LABORATORY, SMITH, KLINE & FRENCH COMPANY,
PHILADELPHIA, PA.

THE ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Proceedings of the stated meeting, held Tuesday, November 28, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 28, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The stated meeting of the Section was called to order by the President.

The minutes of the preceding two meetings were read and approved.

The Treasurer reported $29.14 on hand, and presented bills for postage, printing, etc., amounting to $23.46, which were ordered paid.

The names of Prof. Jos. O. Thompson, Haverford, Pa ; W. Hoopes, Cynwyd, Pa.; J. Appleton, 1007 Spruce Street, Philadelphia; John Brackin, Central Manual Training School, Philadelphia; Theodore B. Lewis, 2025 Pine Street, were proposed for membership and referred to the Committee on Admissions.

A motion was read, to be submitted at the next regular meeting, to amend section 1, article vi, of the by-laws, by striking it out and substituting the following:

Immediately following the annual election of officers, the President shall appoint two members who, with the President, shall constitute a Finance Committee.

This committee shall examine all bills, and such bills, when approved by them and signed by the President, shall be paid by the Treasurer.

In the absence of the President, the chairman of the meeting shall have power to act for him.

Thomas Spencer and P. A. Mitchell were appointed by the President to audit the accounts of the Treasurer.

The following nominations were made for officers of the Section for 1894: For President, E. G. Willyoung; Vice-Presidents, Carl Hering and Prof. E. J. Houston; Secretary and Treasurer, Robert H. Laird; Conservator, Dr. Wm. H. Wahl. Upon motion, the Secretary was authorized to issue tickets for the proposed course of lectures. A motion was also made and carried that the Section assume the expenses pertaining to the lectures.

Adjourned. R. H. LAIRD, *Secretary*.

[*Proceedings of the stated meeting, held Tuesday, December 26, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 26, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The stated meeting of the Section was called to order by President Willyoung.

The minutes of the meeting of November 28th were read and approved.

A motion was also made and carried that the Secretary cast the ballot of the Section for the officers nominated at the regular meeting of November 28th. Upon motion, the further business of the evening was suspended. The President then introduced Prof. H. S. Carhart, of Ann Arbor, Mich., who read a paper on "The Theory and Design of the Closed Coil Constant Current Arc Dynamo."

Adjourned. R. H. LAIRD, *Secretary*.

SUBDIVISION OF STEAMSHIPS AND SAFETY IN CASE OF INJURY.

By Andrew Ham.

[*Read at the meeting of the Section of Engineers and Naval Architects, November 23, 1893.*]

If the skin of a ship is penetrated below water, by a collision, ramming, explosion of torpedo, etc., she may founder by:

(1) The loss of her reserve buoyancy, sending the vessel straight down to the bottom.

(2) The loss of her stability, making her capsize.

Usually, only the first cause is considered, although probably many a ship was lost by the combination of the two causes, as, for instance, the *Victoria*.

The word "reserve buoyancy" means the buoyancy which the water-tight inclosed parts above the water plane can give. It is the weight of a quantity of water, equal in volume to the difference of the total cubical contents of the ship up to the upper deck and the cubical displacement. It is obvious that a vessel must ship a weight equal to the reserve buoyancy before it sinks.

Now, in a ship which has no subdivision, the water has free access to all its parts and, consequently, will flood it till its surface is on a level with the surface of the sea. This may take place without sinking when the cargo is of such a low density that it occupies most of the room in the holds and leaves but little space for the sea to fill; in other words, the ship will float on her cargo. This is, for instance, the case with wooden vessels carrying lumber, some of which are so old and leaky as to be totally unfit for any other trade.

Steel steamships, however, are of too heavy a material to float on any kind of cargo, and to protect them from sinking, the only resource we have is to localize the effects of the injury by subdividing them by means of water-tight bulkheads. Naturally these bulkheads are placed athwart

ships, but in addition to these longitudinal bulkheads may be fitted. Later on, we will see that these may become elements of danger instead of safeguards.

Water-tight subdivision is no invention of the present time, as the Chinese junks were built with bulkheads centuries ago. H. B. M. S. *Etna* and *Terror*, wooden sailing ships, were built with bulkheads as early as 1830, and these effectively prevented the *Terror* from sinking when damaged.

When steam was introduced as motive-power, the necessity of separating the machinery from the cargo holds created two bulkheads amidships. In addition to these a collision bulkhead near the stern was fitted, so that the early steamers had at least three bulkheads, dividing them into four compartments.

The Board of Trade made the fitting of bulkheads compulsory by the provisions of the Merchant Shipping Act of 1854. Lloyds Register Committee followed in 1855 by prescribing two engine-room bulkheads, and one at each end of the vessel.

Since then, as the size of the ships increased and their construction was improved, the number of bulkheads required became larger, and more stringent rules for their construction were laid down.

At present, Lloyds requires a collision bulkhead, a corresponding one near the stern, engine-room bulkheads and one in the fore hold for vessels of over 280 feet long; one in both the fore and aft holds in vessels of over 330 feet long. The question of subdivision has been thoroughly investigated by the Bulkhead Committee appointed by the Board of Trade, which brought out its report in 1891.

It classifies ships in six grades and requires a division in compartments, such that the ship keeps afloat under certain conditions, different for each grade. The first grade comprises all passenger ships over 425 feet long, and, because of the danger in crossing the track of so many other steamers, all channel steamers, irrespective of their length. They must be able to keep afloat with any two of the compartments filled, necessitating in general eight bulkheads.

Ship-owners, especially of large liners, have often fitted more bulkheads than are required either by the Board of Trade or by Lloyds, and wisely done so, for it may be said that their regulations are not sufficient when the safety of so many lives is to be insured.

It is of the highest importance to calculate in an early stage of a ship's design the probable effect of any injury done to the ship.

In these calculations we always suppose the ship to receive the damage at one of the bulkheads, so that the two adjacent compartments are flooded, this being the worst possible case.

Further, the compartments are not supposed empty but filled with cargo. Therefore, to get the weight of water admitted, a certain percentage is deducted from the weight of water which the empty compartment would ship. Or, to put it in another way, not all the buoyancy of the compartment is lost as the cargo displaces water; consequently gives buoyancy. Coal, for instance, admits forty cubic feet of water for every 100 cubic feet of space occupied. Similar deductions are made for engine and boiler space. This deduction for cargo spaces is justified by the fact that they are only empty when the ship has no cargo at all, for no captain will load his ship with a heavy cargo in all except one or two holds, and leave those empty. And when a ship is in light condition she is in general safe enough.

A question, the solution of which may be of practical use in comparing ships or in comparing the preliminary design of a ship with ships in existence, is: How will the safety of a ship be affected when we suppose some of her dimensions altered, as, for instance, her length, or width, or depth?

Let us suppose we have a ship A, having a certain distribution of bulkheads, and let this ship, in case two compartments are flooded, acquire an increase of mean draft α and an increase in total trim β.

What will be the corresponding increments for ships—

B, which is n times the size of A, all round;

C, which is n times as broad as A, keeping the same length and draft;

D, which is n times as long as A, keeping the same breadth and draft;

E, which has n times the draft of A, keeping the same breadth and length?

In changing the length, or breadth, or draft, I suppose the lines to be drawn out in the proportion $1 : n$ in the longitudinal, transverse or vertical direction, respectively; in other words, the character of the lines stays the same and all coëfficients are the same. Also, in changing the length, I suppose the bulkheads to be distributed in the same manner, *i. e.*, a bulkhead (say) sixty feet aft of x in A will be $n \times 60$ feet aft of x in B and D. The effect will be:

B will have an increase in draft $n\,\alpha$, will have the same angle of trim and, consequently, an increase in total trim $n\,\beta$.

C will have exactly the same increase in both draft and trim α and β.

D will have, approximately, the same increase in draft and the same total trim, the error being on the safe side for the longer ship.

E will have, approximately, an increase in draft $n\,\alpha$ and an increase in total trim $n\,\beta$, with the error on the safe side for the shallower ship.

So that, generally speaking, long ships are a little safer than short ships; ships with fine water lines somewhat safer than those with full lines.

Shallow ships are decidedly safer than deep-going ships, and a ship with V-formed sections will be safer than a ship with full or U-formed sections.

It is to be observed that draft and depth in hold should not be mixed up. The greater the depth in hold with the same draft, the greater are freeboard and reserve buoyancy and the safer the ship is.

As before stated, an allowance is made in the calculations for the buoyancy which the cargo gives. But there are other considerations, other factors of safety, or rather, factors of danger, which we cannot express in figures.

The vital parts of the ship are its machinery and the steering apparatus, which latter is under these circumstances of even greater importance than the propelling machinery. This, however, is generally safe, protected as it is by the overhanging upper works at the after end.

The chief advantage of twin-screw ships is found in the possibility of navigating with one set of engine and propeller when the other one is disabled. This requires a longitudinal bulkhead which should be fitted in all twin-screw steamers, and should be extra strong.

The loss of the *Victoria*, however, has shown the danger of capsizing to which a ship may be exposed by having too much of a good thing in this regard.

In an ordinary large liner the angle of heel, caused by the filling of one engine-room will not be so very large, won't exceed 15° probably. But, to counteract this, we would have to fill the water bottom on the emerging side, which would only partly right the ship, and, on the other hand, sink her deeper. Coal might be shifted, but that is neither easily nor quickly done. So that, for the time being, the ship is in a pretty awkward condition. The water pounds against the bulkhead with every roll the ship takes and may wreck it. It is true that statically it acts as a ballast, but dynamically it behaves like a mad bull; possibly throwing its momentum on the ship's side just when she takes a deep lurch, overcoming the margin of stability which is left.

If the water be confined to the engine-room the danger is not so imminent, but if the boiler-room should be flooded, too; and have a longitudinal bulkhead, it may be a serious case. Fitting longitudinal bulkheads in both engine and boiler-rooms, therefore, is inadvisable.

And even where large side bunkers are situated alongside the boiler compartments, it may be well to connect them by a trimming pipe, which may be below the fire-room floor, so that the bunkers on both sides shall become flooded.

The Bulkhead Committee considers a ship unsafe when the deck at the lower side is about three-hundredths of the depth of the ship above the water surface.

Flooding of boiler-rooms means loss of motive-power

entirely, and for that reason in large liners two boiler-rooms are necessary, and it is desirable that the arrangement should be such that (say) a couple of single-ended boilers should be put in a third compartment, which may be smaller.

The main steam pipes, running from the forward boilers to the engine, receiving on their way the steam from the after boilers, deserve a little attention, too. They should be inclosed in a separate trunk, running from the forward boiler compartment through the after one. Valves in the branch pipes to the separate boilers should be situated in or near this trunk and should be made so that they may be manipulated from the upper or main deck. The advantage of this arrangement is obvious. For suppose one compartment flooded and the steam pipes immersed, I think they would form an undesirable condensing apparatus, as ordinary coating is inadequate against the great cooling effect of water.

And, if we could not readily at all times shut off an immersed boiler from the main pipe, this boiler would act as a powerful condenser, too.

Next, we have to consider the donkey boiler, on which the dynamos, the pumps and the other auxiliary machinery depends when the main boilers are powerless. Instead of placing it low down in the ship, it should be put on the main deck and inclosed; or, if placed below, it should be given a separate room, accessible from above by a water-tight trunk. On this poor donkey boiler, which is always in the road when a design is made and is generally being kicked about till it gets in some corner, depends more than is usually supposed.

Finally, no doors should be cut in bulkheads unless absolutely necessary. In the *Columbia*, of the Hamburg-American line, no doors below the water-line are cut in any bulkhead; in the *Lucania* only a very few which were considered absolutely necessary.

Although this gives a lot of trouble to the engineers, it is necessary for safety. For water-tight doors, in perfect working condition when new, after a while get rusty, dusty

or jammed up, and in fact I am afraid that on many a ship they cannot be worked at all. Also, should they work all right in ordinary condition, they might refuse to do so when a strong water-pressure is on one side.

The transverse stability of a ship is considerably changed by the flooding of compartments. As an investigation in this direction offers some interesting points, and, I think, is new to most of us, I will briefly treat this point.

Let us first suppose that the ship is kept in the upright position by a couple of forces, this couple being equal but opposite in sense to the moment of the water in the flooded

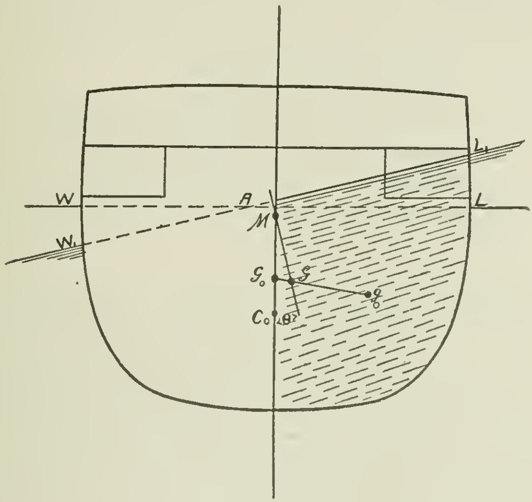


FIG. 1.

engine-room taken about a point on the centre line of the ship.

Then we may find, by known methods, a new water-line $W L$, at which the ship will be in equilibrium after having acquired a certain increase in draft and trim. For we have to treat the case simply as if the compartment were in the centre of the vessel.

It is clear that, as soon as the steadying couple ceases to act, the ship will heel over till a position of equilibrium is found, $W_1 L_1$ being the new water-line. This will be the final position which we must determine.

[*To be continued.*]

BOOK NOTICES.

Encyclopédie scientifique des Aide-Mémoire. Paris: Librarie Gauthier-Villars et fils. Quai des Grand-Augustins. 55.

The publishers of this excellent series of technical hand-books are rapidly completing them. They will form, when completed, an extremely useful library of reference upon a wide range of subjects relating to the applications of science. Each volume is complete in itself, a feature which will be appreciated by those who are interested only in a limited number of the subjects treated of in the series; and the price, 2·50 francs, unbound, and 3 francs bound, of the separate brochures places them easily within the reach of all.

The recent additions to the series, which have lately appeared embrace the following titles, viz:

Sinigaglia, Francesco. *Accidents de chaudières.*
Laurent, H. *Théorie des jeux de hasard.*
Vermand, P. *Les Moteurs à gaz et à pétrole.*
Wallon, E. *Choix et usage des objectifs photographiques.*
Hébert, A. *Examen sommaire des boissons falsifiées.*
Guenez. *La Décoration céramique au feu de moufle.*
Naudin (Laurent). *Fabrication des vernis. Applications à l'Industrie et aux Arts.*

Les Courants Polyphasés. Par J. Rodet et Bosquet. Paris: Librairie Gauthier-Villars et fils. 1893. Large 8vo. Illustrated. Price, 3·50 francs.

This volume is a very satisfactory treatise on one of the most interesting and important of the recent developments in the field of electricity, which promises to play an extremely valuable role in the solution of the problem of the transmission of power to a distance. The authors discuss the subject under five chapter heads. Part I is historical and theoretical. Part II treats of diverse generators of polyphase currents. Part III treats of motors, synchronous and asynchronous. Part IV is devoted to transformers, and Part V to the circuits and the general subject of installation. The work is appropriately concluded by a description of the installations for long-distance transmission at Frankfort-on-the-Main, at Heilbron on the Neckar, and at Buda-Pesth. The work should be specially useful to electrical engineers.

W.

Premiers Principes d'Électricité Industrielle. Par Paul Janet, Professeur de Physique, chargé du cours d'électricité industrielle à la faculté des sciences des Grenoble. 8vo, 270 pp., 173 figures. Price, 6 francs. Paris: Libraire Gauthier-Villars et Fils. 1893.

Just why this work should have received the title it bears above is a mystery, since *principles* seem to have been but little thought of by the author in its writing. A more fitting title would have been *Une Encyclopédie abregé.*

We are indebted to the French for much of the best scientific and engineering work that has been done; especially are we under obligations to them for many of our most authoritative published guides. It is, nevertheles, true that there is a considerable school of French scientific writers who believe that pages and pictures make up a scientific work. The publication above is of this character. Devoid of mathematical, even arithmetical treatment, some 165 pages are devoted to dynamo machines, motors and transformers; the sizes of the machines, the direction of the current in the field, etc., are given with brevity and in a juvenile vein. Voltaic cells and accumulators are described and classified in detail; the chemical reactions and considerations of power involved are, however, completely neglected. That the paper and print are excellent goes without saying, and in this respect the work can be heartily commended. Beyond this the writer can only say "every man to his taste;" if the French admire this style of literature, well and good; Americans, certainly, have no time to read it, except possibly as an exercise in reading scientific French. E. G. W.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, December 20, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 20, 1893.

Mr. WASHINGTON JONES in the chair.

Present, sixty-two members and twelve visitors.

Additions to membership since last report, twenty-seven.

The Secretary reported the following action taken by the Committee on Science and the Arts, at its stated meeting of December 6, 1893, viz:

The Committee on Science and the Arts reports to the Institute the following resolution and recommends its adoption:

Resolved, That the President and Secretary of the Institute be authorized to affix their signatures and the Secretary to affix the seal of the Institute to all reports of the Committee on Science and the Arts, when finally adopted by it, setting forth that such reports are the action of the Franklin Institute, by its Committee on Science and the Arts.

The resolution was thereupon presented to the meeting, and on being put to a vote was adopted without dissent.

The following nominations were made:

For *President*	(to serve one year), . . .	JOSEPH M. WILSON.
" *Vice-President*	(" three years), . . .	W. P. TATHAM.
" *Secretary*	(" one year), . . .	WM. H. WAHL.
" *Treasurer*	(" " "), . . .	SAMUEL SARTAIN.
" *Auditor*	(" three years), . . .	W. O. GRIGGS.

For the *Board of Managers* (to serve three years).

ARTHUR BEARDSLEY,	*HENRY BOWER,	CHAS. A. BRINLEY,
WM. BURNHAM,	CHAS. G. DARRACH,	*HENRY R. HEYL,
*H. W. JAYNE,	M. R. MUCKLE, JR.,	*HENRY PEMBERTON, JR.,
HORACE PETIT,	*WM. SELLERS.	

For the *Committee on Science and the Arts* (to serve three years).

H. BRINTON,	SPENCER FULLERTON,	S. P. SADTLER,
JOHN E. CODMAN,	W. C. HEAD,	CLARENCE B. SCHULTZ,
H. F. COLVIN,	HENRY R. HEYL,	THOS. SHAW,
THOS. P. CONARD,	FRED. E. IVES,	E. G. WILLYOUNG,
CHAS. B. DUDLEY,	C. L. PRINCE,	PAUL A. WINAND.

Mr. Pedro G. Salom presented a communication on the results recently obtained in Germany and elsewhere abroad by the use of the storage battery in central station work, which exhibited decided advantages in respect of economy and general efficiency over the usual system of transmission by generators. (Referred for publication.)

Prof. Lewis M. Haupt, by request, presented a paper, entitled "The Manchester Ship Canal and its Moral." In this paper the author stated the reasons which appeared sufficient to justify the city of Manchester to assume the responsibility of expending the enormous sum of $75,000,000 for the construction of a ship canal (thirty-five and one-half miles long) and auxiliary works. He gave a brief outline of the engineering features of the work referred to, the great difficulties encountered in its construction, the large interests enlisted in opposing its progress, and the economies to be secured by its completion, in avoiding the payment of the terminal charges of Liverpool and of the railroads. The speaker made use of the exam e of the Manchester Canal to show by comparison how much more important would be the beneficial results flowing from a ship canal connecting Long Island Sound with the Chesapeake Bay. The paper was discussed by Messrs. Salom, Smith, Fullerton and Eldridge, and was referred to the Committee on Publications. A vote of thanks to the author for his interesting and suggestive paper was unanimously passed.

Mr. T. Carpenter Smith gave a description of the new Westinghouse incandescent electric lamp, with removable base, and illustrated his remarks by an interesting series of specimens. The subject was discussed by Messrs. Eldridge, Salom, the Secretary and the author.

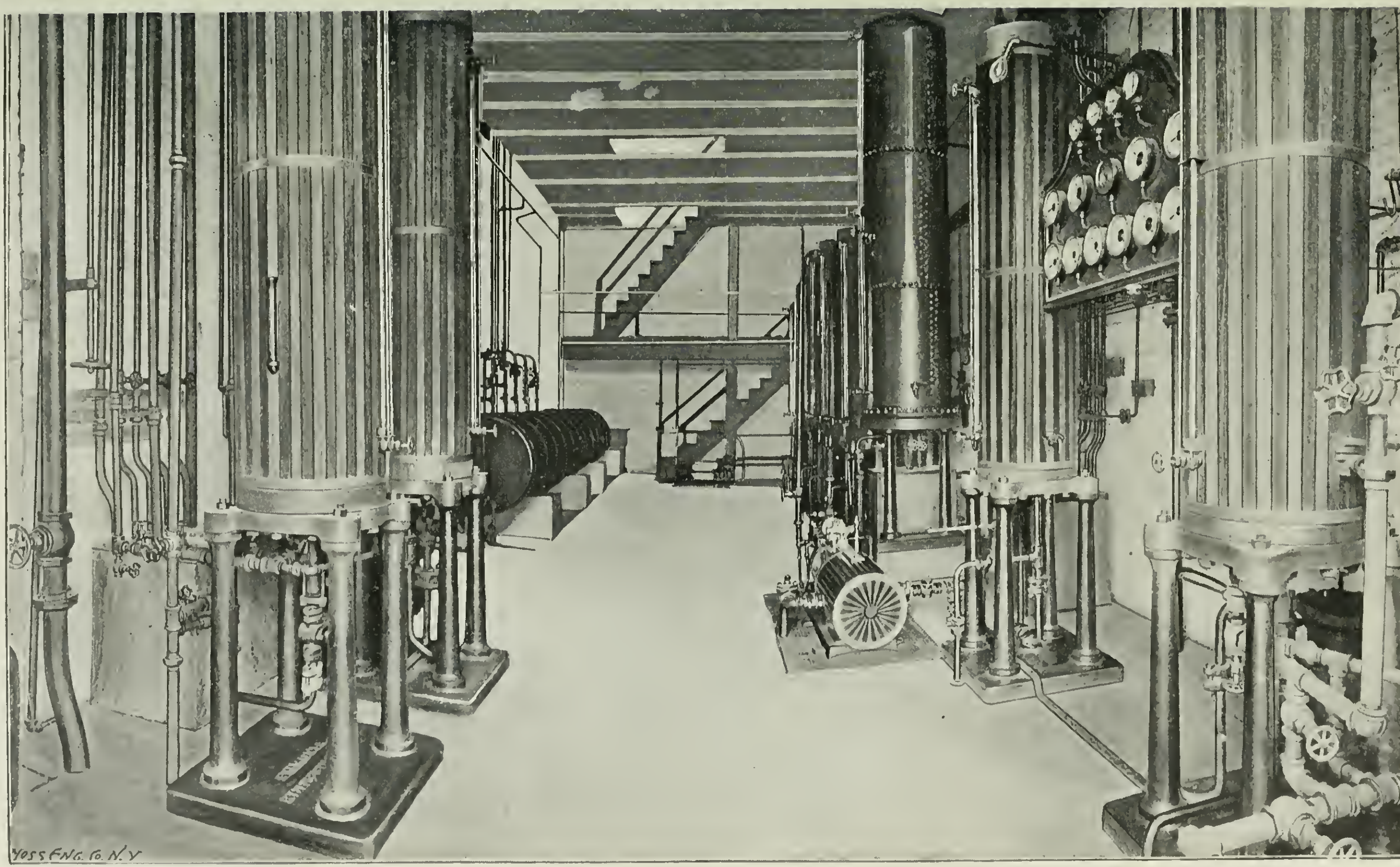
Mr. S. Lloyd Wiegand gave a description of the type-writing machine invented by Jas. D. Dougherty. This is a machine of the type-bar class, embodying, in the speaker's estimation, a number of substantial improvements. The speaker illustrated the subject by use of lantern slides, models of details, and the exhibition of a working machine.

On motion, the invention was referred to the Committee on Science and the Arts for investigation.

The Secretary made a brief report, whereupon the meeting was adjourned.

WM. H. WAHL, *Secretary.*

* Retiring members.



INTERIOR VIEW OF POWER HOUSE, COLORADO AUTOMATIC REFRIGERATING COMPANY, DENVER, COL., 1889.

JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXXXVII. FEBRUARY, 1894. No. 2

THE Franklin Institute is not responsible for the statements and opinions advanced by contributors to the *Journal.*

ARTIFICIAL REFRIGERATION THROUGH STREET PIPE LINES FROM CENTRAL STATIONS.

BY DAVID BRANSON.

[*Read at the stated meeting of the Institute, November 15, 1893.*]

The methods of distribution from central stations through street pipe lines, or wires, of water, light, power, heat and speech, have all been made somewhat familiar to the public by years of common usage. That of distributing power to produce cold is known to comparatively few, and in its latest development, made during the past four years, is, as yet, almost unknown.

A popular idea prevails that we furnish cold air. As a matter of fact, we do not send out cold air, or anything cold, through our pipes. All such methods have been, and must be, financial failures, in spite of the most costly insu-

lation, because of the percentage of loss of cooling power through absorption of heat from the earth or air through which the pipes pass.

Correctly speaking, our business is not to furnish anything; but to remove from the premises of our customers two things of which they wish to be rid—heat and humidity.

The most suitable material, as well as by far the cheapest, which can safely be used as a heat extractor, is ammonia. It conveys heat to the central station, where the heat is disposed of through an application of cold water; and the water, after being thus loaded with heat, is ordinarily discharged into the sewer.

To make the illustration more clear to those having no knowledge of ice-making or refrigerating machines, it might be well to explain by saying that expanding ammonia absorbs heat and that water absorbs ammonia, just as a sponge absorbs water. One might say that water is a sponge for ammonia, and ammonia is a sponge to sop up heat.

Since the first practical development of artificial refrigeration and its application to the cooling of breweries and packing-houses, and to ice-making, it has been the dream of many inventors, and also the aim of industrial promoters, to achieve a practical, safe and economical method of distributing refrigeration. Some twenty or more costly efforts to accomplish this result had been made in a dozen different cities, including Paris, London, New York, Boston, Louisville and Nashville. These resulted either in failure or in only partial success, but there was a great gain of valuable knowledge of the difficulties to be overcome, with little knowledge of how to overcome them, until five years ago, when Messrs. Starr, Thornburgh and Branson, the inventors of the system which we are to discuss this evening, undertook to study the causes of the failures of their predecessors.

Fortifying themselves with all the data that could be obtained, they experimented extensively, and visited many of the wrecks of other experiments.

The result has been a series of inventions which have been put into practical operation on a commercial scale in the cities of Denver and St. Louis. The plant in Denver

was started on the eighth of August, four years ago, and has not been obliged to stop a single day since, though it has been twice enlarged and the street line extended. The street line in St. Louis has also been operated for more than three years. Both plants give such satisfaction to their patrons that many would not return to the use of natural ice could they procure it for nothing.

Let me quote from an able article by John E. Starr, which appeared in the *Engineering Magazine* for April, 1893:

"Up to the introduction of the pipe-line system, only those who required large amounts of heat to be transferred could afford the appliances necessary to effect such transfer without using ice as an intermediary. To such large consumers of cooling power the introduction of ice machinery has been of incalculable value. In the brewing, meat-packing, dairy and cold-storage warehouse industries, the refrigerating machine saves annually millions of dollars, and renders possible operations on an enormous scale. To secure to the smaller consumer the benefits, and to the vendor the profits, of mechanical refrigeration was the problem of the pipe line engineer. The general economical advantages required to be preserved may be stated as follows:

(1) "The realization of enormous economy by operating in such a way as to transfer the heat directly from the customer to the central station without using ice as an intermediary.

(2) "The great economic advantages in distribution.

(3) "The general advantage of producing power on a large instead of on a small scale.

(4) "The commercial advantage of being able to offer to the smallest consumer of refrigeration all the benefits and economies of artificial refrigeration now obtained only by large consumers.

"To explain more specifically the first of the above considerations, it may be said that all refrigerating machines have two ratings, one known as their 'refrigerating capacity,' expressed by stating how much ice must be melted to produce an equal cooling effect; and the other as their 'ice making capacity.' The latter is usually placed, at the out-

side, at only sixty per cent. of the former; that is to say, if we have a refrigerating machine that will produce as much cooling power as could be obtained from 100 tons of ice if placed directly at work on the space to be cooled, this machine would manufacture only sixty tons of ice. This may be more readily understood when it is remembered that in ice making the water which is to be frozen has first to be cooled by the machine from a temperature of 80° or 90° F. to the freezing point, before the process of congelation begins. This loss, together with the absorption of heat in and around the ice-making tank, makes up the forty per cent. difference; and this is why all refrigerating machines are catalogued commercially with the two ratings mentioned.

"In the pipe-line process the refrigerating machine is put directly at work on the spaces to be cooled. When a central plant has the equivalent of 100 tons of ice to deliver to its customers, the artificial ice plant has, with the same machine and the same expenditure in coal and engineer's wages, but sixty tons to deliver. This leads to the second consideration. The sixty tons of artificial ice, with the expense mentioned, are delivered only at the factory door. The 100 tons at the station have been delivered to the customers.

"The delivery of ice, even to large customers, is one of the principal factors of cost, while to smaller consumers, say of from fifty to 500 pounds per day, the delivery is by far the greater portion of the cost. The service of ice requires usually a team of horses, a wagon, and two men for delivery in a comparatively limited district, and the cost of delivery by this method usually ranges from fifty cents per ton for the larger consumers up to $2.50 per ton for the users of small pieces of from ten to 200 pounds per day. This large 'operating cost' of delivery, which, to the ice dealer, is an item of expense, becomes to the pipe-line company an item of profit. The upkeep, or repair, account, is little, if any more, by the pipe-line method than by the horse and wagon system of delivery."

At the outset of our attempt to construct and operate

our street pipe-line system, we found that the principal obstacles were:

(1) The loss of power by absorption of heat from the earth.

(2) The difficulty of handling the constantly changing refrigerating load.

(3) The occasional stoppage of service of an entire district by reason of fire or breaks in the line, through accident, or the necessity of making new connections.

(4) The automatic regulation of temperature.

(5) The leakage of the volatile material used as a refrigerating agent.

The absorption of heat from the earth is avoided by what is known as a direct expansion system, in which the liquid anhydrous ammonia (usually at a pressure of 150 pounds to the square inch at summer temperature), flows from the machine through one pipe (the liquid line) to the point of use, and is there expanded by being allowed to flow through a small hole, in a carefully adjusted valve, capable of being regulated to suit the amount of refrigeration required. This expansion takes place in a coil of pipe, within the space required to be cooled, which pipe is known as the expansion coil; and from this coil the anhydrous ammonia, now changed to a vapor, returns through a larger pipe (the vapor line) to the central station. By this system, the entire cooling power of the machine is delivered and utilized in the refrigerators of the customers, none being lost on the way. The pipes, with the exception of the expansion coil, remain at the temperature of the ground or air through which they pass.

Our predecessors had managed fairly well to provide regular temperatures in large establishments under the changing conditions of the seasons, or of day and night, by increasing or lessening the number of machines in operation or the speed at which a single machine was operated. But this had its limitations both financial and mechanical.

In the street pipe-line business this difficulty is increased tenfold. Experience soon taught us that no possible calculation could enable us to predict when the demand upon the

machine would suddenly rise tenfold, without a moment's warning, or as quickly fall to practically nothing.

To provide against this difficulty, we introduced one reservoir (for liquid anhydrous ammonia) at the outgoing end of the machine, a second reservoir (for strong aqua ammonia) at the incoming side of the machine, and a third (for weak aqua ammonia), which is usually placed at a higher elevation.

When the strong aqua ammonia reservoir is full. both others are empty, as their contents are supplied by the separation of the ammonia or the greater part of it, from the water originally holding it in the strong aqua ammonia reservoir. The contents of this reservoir are pumped into the still at a uniform rate, and from the still the pure ammonia passes through the condensing coils to the reservoir for liquid anhydrous ammonia and the water or weak ammonia remaining flows to its reservoir above, each impelled by the pressure obtained from the heat of the distilling process.

The contents of the weak ammonia reservoir flow by gravity to the absorber automatically, as required, and absorb the returning anhydrous ammonia vapor from the street line.

As we use what is known as an absorption machine (because compression machines have been found impracticable for this purpose) the anhydrous ammonia vapor returning from the line is first discharged into a tank of peculiar construction, called an absorber, where it is reunited with the weak aqua ammonia from which it was originally driven by distillation. When this aqua ammonia has absorbed all of the anhydrous ammonia vapor that it is capable of holding, it is automatically discharged into the reservoir for strong aqua ammonia, from which it is again pumped into what is known as the still or separator.

By this reservoir system several objects are accomplished; first, a machine of half the size that would otherwise be needed will answer for any required amount of service; as it will readily be seen that without the reservoir, a machine would have to be of sufficient capacity to perform the ser-

vice called for during the hottest hour of the hottest day, while during other hours a machine of one-tenth the capacity would often be ample.

In the reservoir system, the machine operates steadily throughout the twenty-four hours, while the reservoirs vary in the amount of their contents alternately as the demand reaches a rate greater or less than the average of the machine.

This system also enables us to shut off the machine entirely for short periods to make repairs, and in cold weather, to dispense with a night force entirely, allowing the reservoir and the absorber to work automatically, without attention.

Of course, in very large cities, multiples of the largest sized machine would be used with reservoirs of sufficient size to give steadiness to the operation of either machine and to permit of short stoppages.

Our third great difficulty was overcome by providing a vacuum or safety line, which is a vital part of the system; for, without it, continuous operation could not be secured, nor could necessary repairs be made. This vacuum line is a third pipe connected with the liquid and vapor pipes, at or near their entrance to each refrigerating box supplied, and also in the man-holes at the street crossings.

In case of necessary repairs, alterations or additions to the pipes in any premises, the stop-cocks on the liquid and vapor pipes are closed, and the cock on the vacuum line (which has been habitually kept closed) is opened, the vacuum pump is then started at the station, and thus the ammonia contained in the expansion coil is drawn back to the central station and a ten or fifteen-inch vacuum is also usually produced. Then the piping in the refrigerating box may be opened without any smell of ammonia escaping.

By the same method, any section of the main line may be cut into for additional connections or repairs, by means of opening and closing cocks in the manholes at street crossings.

In our later work we have made the vacuum line of such size that it can be used as a temporary substitute for either

the liquid or vapor line, during alterations, thereby enabling us to avoid cessation of service to any customer even for an hour.

By keeping a constant vacuum, the contents of any expansion coil or any section of the line may, without previous notice to the engineer, be promptly switched into the vacuum line from any place where trouble has occurred, especially in case of fire or break in the street, and thus the material liable to be lost is quickly saved, as the engineer at the works will immediately start the vacuum pump, upon his attention being called thereto by an electric bell rung by the movement of the hand on the dial of the vacuum gauge.

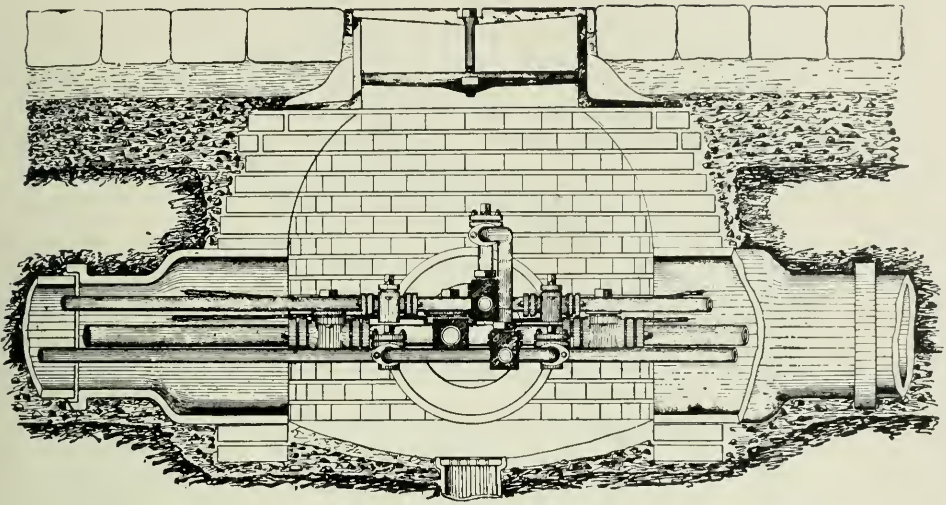
The advantages of this vacuum line are also very apparent when it becomes necessary to shut off a customer, and pump home the contents of his expansion coil, and leave him out in the hot for non-payment of his bill.

In the matter of automatic control we had to solve the problem of supplying all degrees of temperature, not only on the same branch line or street, but often three or four in one building, or even in the different compartments of one refrigerating box; varying from ice-making and fish-freezing, up to the very easy task of keeping rooms for furs and woollen goods free from moths, or taking a few degrees of heat and humidity from a restaurant dining-room, a public hall, business office or hospital.

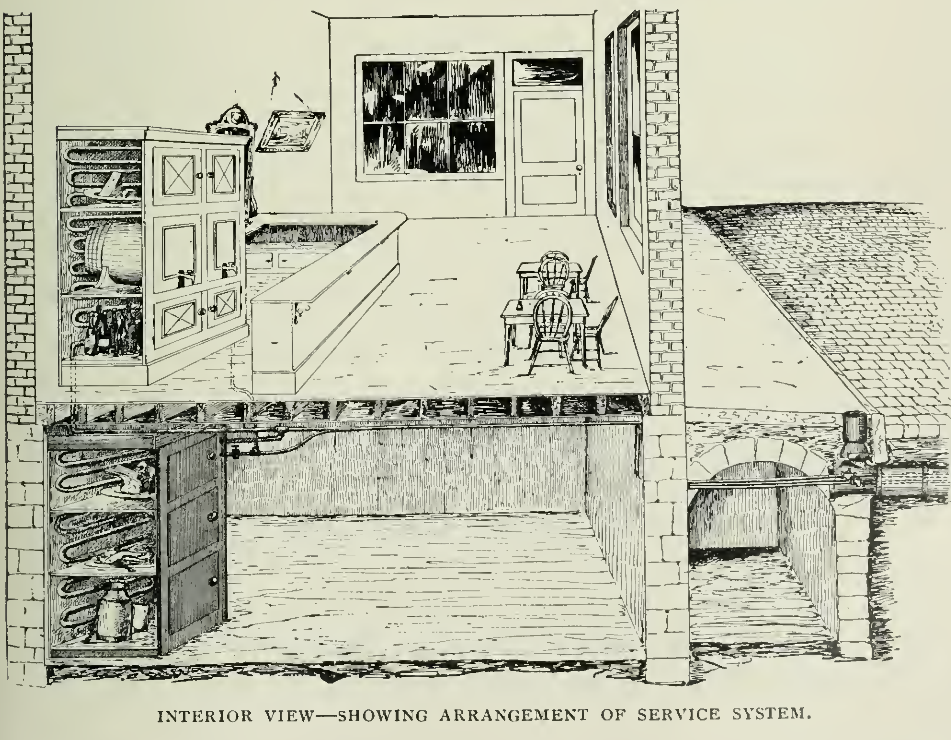
To do this, numerous devices were invented and tested—nearly all with brilliant success at the start; only to be followed by dismal failure when put to the test of time and innumerable changing conditions.

They choked up, froze up, gummed up and broke up in every imaginable way. But, one by one, the weak points were weeded out, the strong features combined; until, finally, two forms of regulators were constructed, both of which have stood the test of every possible condition we could think of through the changing requirements of spring, summer, autumn and winter.

These automatic valves are operated by electric power supplied from a dynamo through a storage battery at the



SECTIONAL VIEW OF MANHOLE, SHOWING ARRANGEMENT OF PIPE LINES.



INTERIOR VIEW—SHOWING ARRANGEMENT OF SERVICE SYSTEM.

central station; thence through an insulated copper wire circuit laid in the same conduit which contains the pipe line, and they are caused to open and close by the action of an ordinary thermostat placed in the cooling box and easily adjusted by thumb screws to any required temperature. We ordinarily set them to open the valves at 1° above and close them at 1° below the average temperature required; though, with careful manipulation, they can be adjusted so as to permit of much less variation. In the preservation of eggs, for instance, we do not permit a variation of more than one-half of 1°; and, as a consequence, have had remarkable success in the preservation of this most perishable product.

In connection with the automatic valve the electric circuit can be used to signal from any refrigerator on the line to the engineer at the station; and one form of valve is so constructed that, if it should get out of order, an electric bell would ring in the engine room until the valve is attended to.

The most obstinate difficulty in mechanical refrigeration was the leakage of ammonia or other volatile gas used as a refrigerating agent; but constant experiment finally evolved a series of fittings and packings for joints which have been found practically perfect under continuous use for more than two years; both under and above ground, in wet places and in dry, in heat and in cold; and after being subjected purposely to all kinds of abuse.

Provision is made in their construction for contraction and expansion of long and straight lines of piping; even when, through carelessness, there might be a sudden change of temperature of over 100°.

The absorption machine which we use does not radically differ in construction from some others, aside from the reservoir feature, and the automatic regulation of the discharge from the absorber. But we have made in it, during our four years of commercial operation, several minor changes, each adding to its efficiency, reliability and economy, and lessening the amount of intelligence required to operate it safely.

The question of measurement of the amount of service rendered has been solved in two ways:

First, by a meter, measuring the quantity of liquid ammonia passing into each expansion coil. Knowing as we do the heat-extracting power of a pound of ammonia expanded under any given condition, it is a simple matter to calculate the equivalent, in ice melting, of the service rendered.

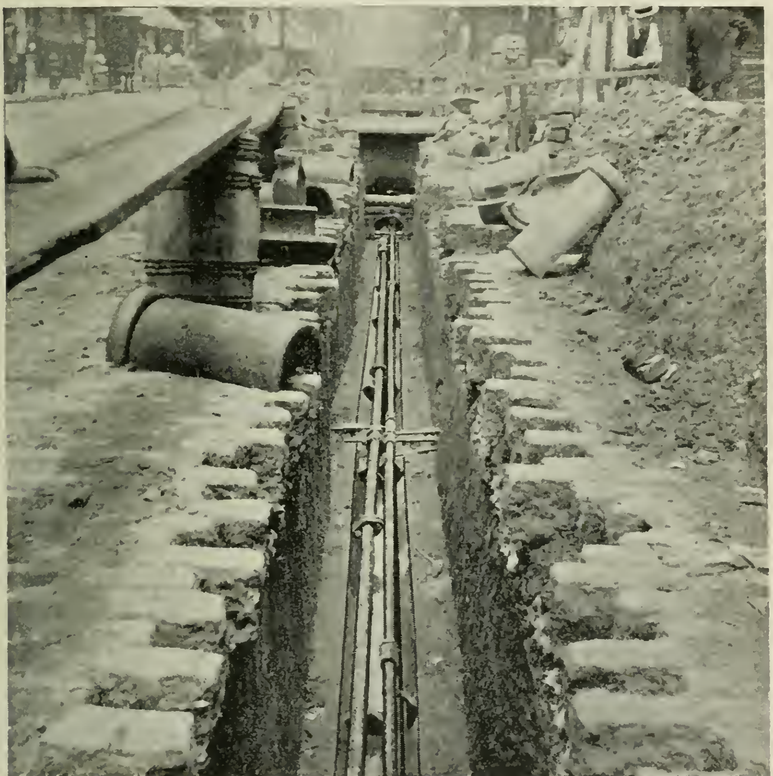
Up to the present time, no cheap meter has been made for the measurement of ammonia, which is even as satisfactory as the ordinary illuminating gas meter; and we hope for something less costly for this purpose before undertaking general household service.

The second method of estimating the amount used is the measurement of the square feet of the interior surface of the refrigerating box or room, and the figuring out of the amount of heat removed therefrom, by the aid of a set of tables carefully prepared by means of a long series of experiments with every known form of insulation now in general use for refrigerating boxes.

By these experiments we have ascertained, as to each material and thickness, how many units of heat will pass through a square foot of service in twenty-four hours for each degree of difference between the average inside and average outside temperature. To this we add a small percentage (based on experiments) for the amount admitted by the opening of doors, and the placing of hot materials in the refrigerator.

The entire cost of street-line construction varies from $9,000 to $22,000 per mile, depending upon the character of the street-paving, which has to be removed and replaced, the kind of soil to be excavated, the crowded or free condition of the ground under the streets from other piping, etc., the correctness of the city records as to old work in the same, and the amount of street traffic interfering with operations. The highest cost has been in narrow, crowded business streets in St. Louis, Mo., where the paving is very expensive, and where there was a net-work of both old and new pipes, of many of which no correct record existed in the city

archives. This frequently necessitated the changing of plans after the streets had been opened. In a city with pavements of average character, the cost, including branches to the sidewalk, ready for service connections to the num-



REFRIGERATING PIPE LINE, IN PROCESS OF CONSTRUCTION, SIXTH STREET, ST. LOUIS, MO., JUNE, 1891.

Showing the open trench in which is first laid the lower half of each section of vitrified clay pipe which forms the conduit in which the wrought-iron pipes conveying ammonia are laid upon suitable brackets. These brackets also support the insulated copper wire for the electric circuit.

ber of 100 to the mile, will be about $18,000 in business neighborhoods, and about $14,000 in residence districts where the lines can generally be run through back streets containing no other pipes.

A power house* with duplicate machines to operate two or three miles of street line in a business locality, should not exceed in cost $90,000. In large cities it would be better to build a larger plant, say one costing $200,000, with five or six cooling machines of daily capacity of 100 tons each. This should take care of five or six miles of street line. Should it be required to cover more ground than this, in very large cities, it would probably be better to build another plant at a distance not exceeding two miles from the first. The limit of practical working distance is about the same as with illuminating gas.

It is immaterial whether the plant be on low or on high ground, or whether the lines run down or up hill, or both, alternately. It can be operated on any floor of a building, from cellar to garret; and it is now supplying cold on the second floor of a large hotel some thirty feet above the street line and fifty feet above the central station. We have made no failure in any kind of cooling operations that we have attempted. These have covered nearly the entire range of cooling work (including ice making in the buildings of customers at long distances from the works).

We have, so far, charged prices varying from ten to twenty per cent. less than would be paid for ice sufficient to furnish an equivalent amount of cooling. In addition to that saving in their ice bills, customers have avoided slop, wear and tear, and have saved the cost of labor in handling ice. We also give them much more uniform service, and in many cases do work which it is impossible to do with ice; especially continuous and hard freezing and furnishing dry cold where damp cooling with ice would be ruinous.

While it is, of course, not only probable, but certain that numerous improvements will be made in the apparatus, from time to time, they will be mainly in the line of minor

* The frontispiece shows an interior view of the power house of the Colorado Automatic Refrigerating Company, in Denver, erected in 1889. Horizontal tank, strong aqua ammonia reservoir. Upright tanks near the stairway, liquid anhydrous ammonia reservoir. The largest upright cylinder is the absorber. Cylinders in the foreground on each side are stills and exchangers. The weak aqua ammonia reservoir is on top floor.

economy; the system itself, and general operation being substantially perfected. The repairs on the work constructed two years ago, after we had finished experimenting on the original trial lines, have been only nominal, and the loss by leakage small, and this due to the carelessness of employés. By the improved fittings, leakage has been made almost impossible.

We operated, at first, with machines of twenty to thirty tons daily capacity; and continued to do so until more than two years ago, when a ninety-ton machine was added in St. Louis. This has been working successfully ever since, and a duplicate has since been used in connection with it. Another of the same size was put in operation eighteen months ago in Denver, and is working satisfactorily. The old machines are being utilized in the business of ice making; and at the same time are in readiness to take care of the street-line work in case the new machines should by any chance get out of order; in which event, the ice-dealers only would have to fall back on their store of natural ice.

The USE of STEEL in ELECTRIC MACHINES.

By H. F. Parshall.

During the last few years steel has come to be used largely in the magnetic parts of electrical machines. In the magnet frames of some classes of machines the changes brought about have been most marked. In armature cores which require thin plates there has been no change, since the requirements are so rigid that the properties, either physical, or chemical, of steel, differ but little from wrought iron; in fact, the distinction between steel and iron in this case is made on account of the difference in the processes of steel and iron making.

By the use of steel in magnet frames street-car motors have been so completely changed that the motors of to-day, so far as form and appearance go, are hardly comparable with those of a few years ago. Before it was possible to

get steel castings of complex form, street-car motors were limited to such forms of construction as could be built up with elementary blocks of forged iron.

How great the change has been is evident upon examination of *Figs. 1, 2, 3* and *4*. *Figs. 1* and *2* show two early

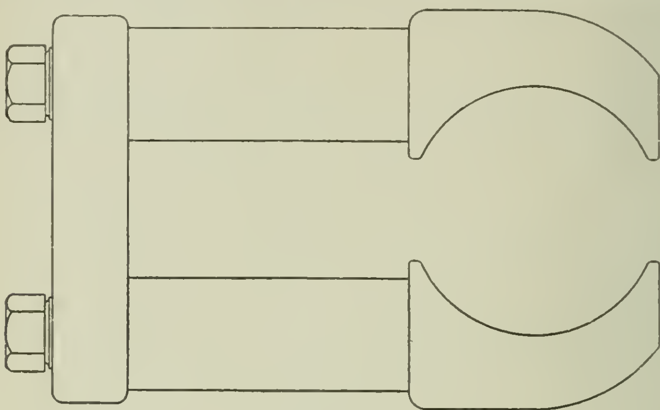


FIG. 1.

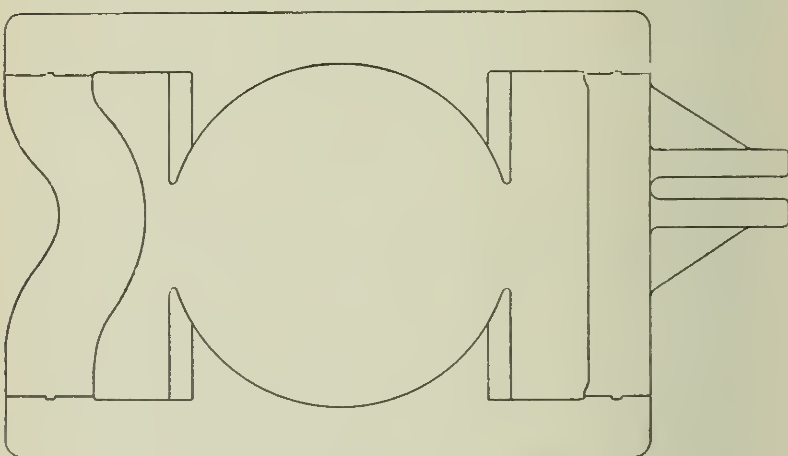


FIG. 2.

types of street-car motors that have been widely used, that were constructed from the forms of iron obtainable when the machines were designed. *Figs. 3* and *4* show the outlines of a modern street-car motor constructed of steel castings. It will be noticed that a water-proof casing has

been cast with the magnetic circuit, that the motor is much more compact, and that the parts liable to mechanical injury are thoroughly protected. The forms of motor practicable to build from forgings do not lend themselves well to single reduction, while with the steel castings now obtainable,

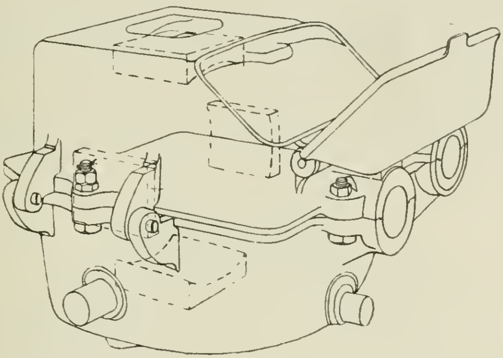


FIG. 3

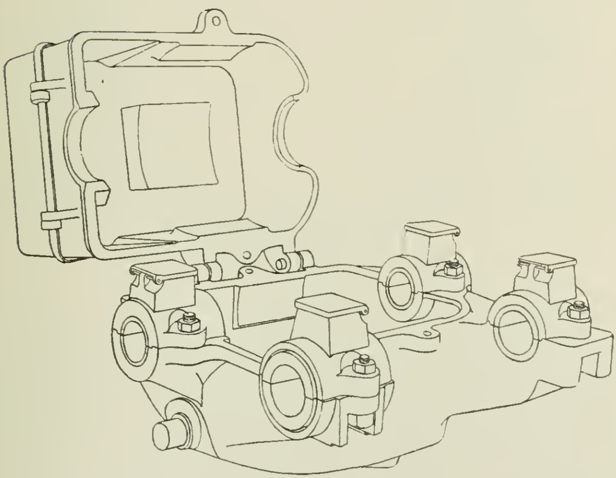


FIG. 4.

single reduction motors are easily constructed and economical of material.

Further, owing to the range of form permissible, it is possible to arrange the parts so that the length of the magnetic circuit is shortened, thereby diminishing the weight

of the motor about twenty per cent. to the advantage of repairs on track and trucks.

In stationary motors corresponding changes have been made, or are now contemplated. In the case, however, of generators the advantages obtainable from the use of steel are less marked, both from the standpoint of form and of economy, the principal reasons being that this class of machinery is not restricted as the above classes as to size, form, or weight.

The ratios of permeability and cost per pound of steel and cast iron, as used in best practice, show a margin of

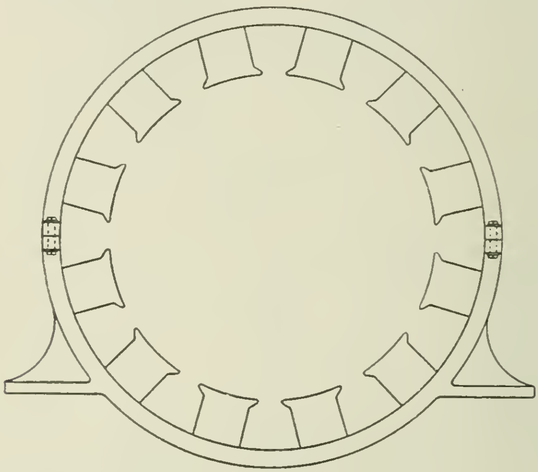


FIG. 5.

about twenty per cent. in favor of the use of steel. The ratios of the permeability to the cost of steel and wrought iron forgings of simple form show a margin of twenty per cent. to twenty-five per cent. in favor of the use of wrought iron.

Reasoning from the above and neglecting any difference in machining, it would appear that magnet frames constructed entirely of steel would be cheaper than those constructed of cast iron. Further, the difference is considerably increased on account of the greater amount of copper required in the magnetizing coils of a cast-iron machine. this increase being due to the greater length of turn of the magnetizing coils on account of the greater section of the

cast iron required to support a given magnetic flux. In the conditions obtaining at the present time steel magnet frames and magnetizing coils cost only about seventy-five per cent. of magnetically equivalent cast-iron magnet frames and magnetizing coils.

It would further appear from the ratios given above, of the permeability and cost of steel and forgings, that a magnet frame constructed of forgings would be the cheapest of all.

By referring, however, to *Fig. 5*, which shows a typical

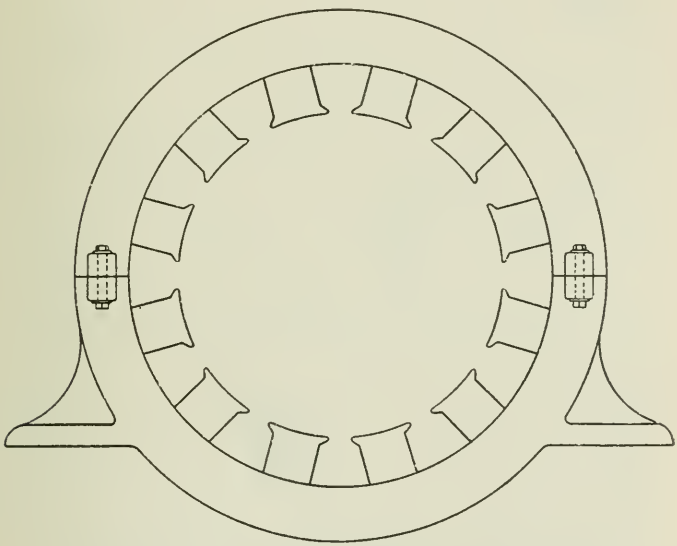


FIG. 6.

magnet frame, it will be seen that it is not practicable now to construct dynamo frames entirely of forgings. It is practicable, however, to construct magnet frames with the yoke of cast iron, the magnet cores of forgings and the polar projections of cast steel, as is shown in *Fig. 6* on the same scale as *Fig. 5*. Such a structure costs about the same as one entirely of cast steel, and possesses the advantage that both cast iron and forgings are more uniform in magnetic qualities, easier to machine, require less chipping and are more easily finished. There is, however, the disadvantage

that the weight of cast iron as used in practice is about two and one-half times that of steel for same magnetic results, and thus the parts that can be made of cast iron are in many cases very massive and difficult to move.

As a practical example, we will take the 1,500 kilowatt generator, recently designed for the General Electric Company, and now in operation in the Brooklyn Railway Station. The magnet yoke is constructed of steel and weighs 38,000 pounds. If it were constructed of cast iron it would weigh

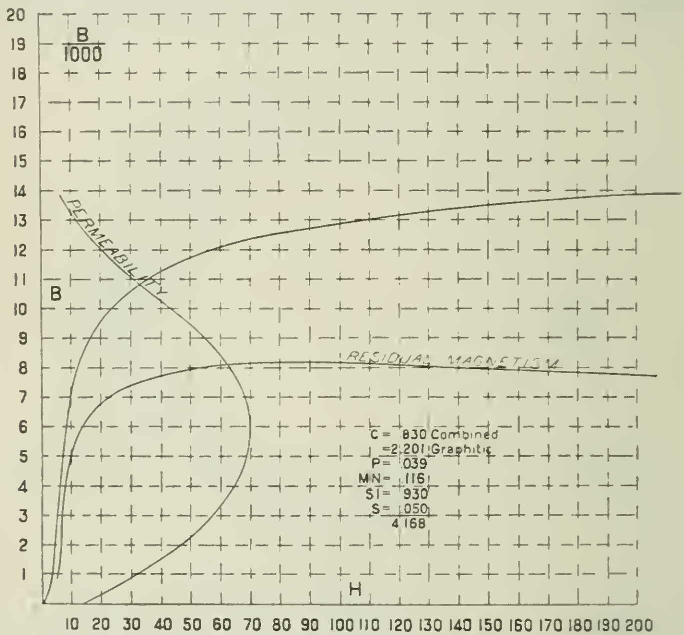


Fig. 7.

87,000 pounds, such a weight requiring extraordinary facilities both as to shipping and handling in the shop.

We will now consider the quality of steel required for magnet frames, meaning by steel such combinations of iron as can be cast and are free from uncombined carbon or graphite. The effect of combined carbon or graphite is to lessen the magnetic continuity and greatly lessen the permeability.

Figs. 7 and *8* have been included to illustrate the mag-

netic effect of the presence of graphite even though, by the above definition, graphitic irons are not directly in the line of the present discussion.

It is the practice of the General Electric Company to make a chemical analysis of a sample of the steel in each casting before it is used in construction. This was occasioned by the considerable variation found in steel made, apparently, under the same conditions. In one notable case the amount of copper in the magnet coils of a large genera-

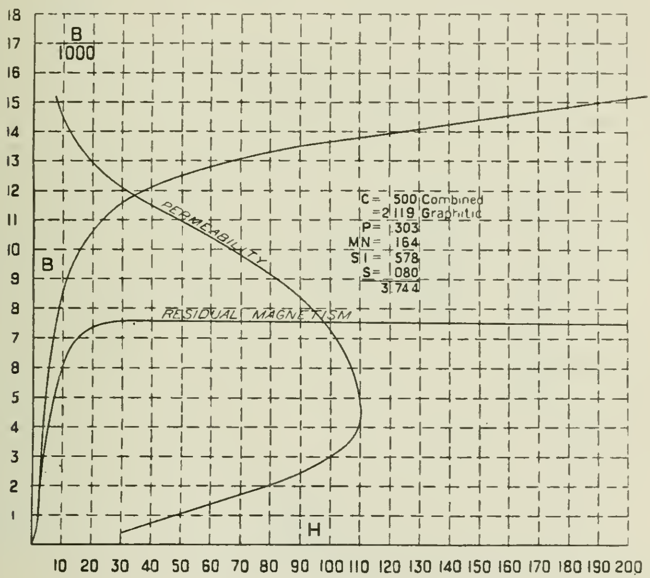


Fig. 8.

tor had to be increased thirty per cent., owing to the presence of innumerable blow-holes throughout the yoke and pole pieces. An examination of a great number of these analyses does not indicate clearly the relation between the chemical and magnetic properties. The particular value of such analysis seems to be from the clue furnished to the physical properties, *i. e.*, as to the probable softness and homogeneity of the steel.

It may, however, be roughly stated that good cast steel

should not have greater percentages of impurities than are given in the following analysis:

Carbon,	·25
Manganese,	·60
Silicon,	·20
Phosphorus,	·08
Sulphur,	·05

In practice, carbon is the most objectionable impurity, and can to advantage be restricted to smaller amounts than above quoted. The results of a great number of tests and

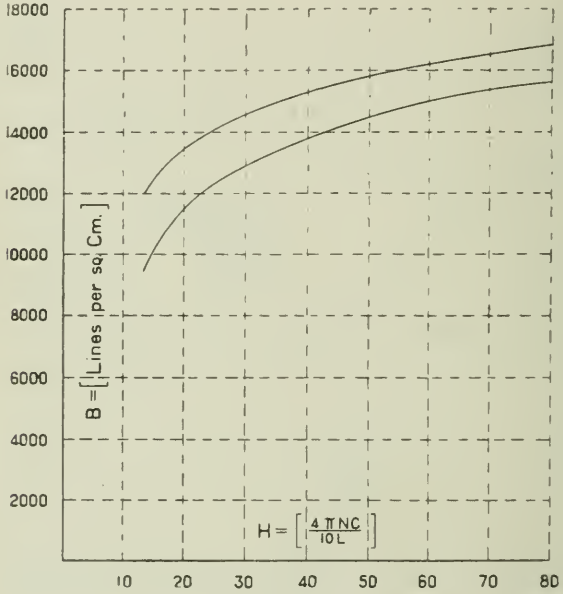


FIG. 9.

analyses were plotted, and it appeared quite evident that the falling off of permeability was proportional to the amount of carbon contained and by diminishing the amount of carbon, other conditions remaining the same, there was a corresponding increase of permeability.

Manganese below ·6 per cent. seems to have but little effect. The presence of manganese in large quantities deprives the steel of nearly all magnetic susceptibility, a twelve per cent. mixture having scarcely greater magnetic susceptibility than air.

Silicon at the magnetic densities used in practice is less objectionable than carbon, but at high densities it appears to diminish the magnetic qualities of iron to some extent. Its presence is objectionable in that it facilitates the formation of blow-holes, and like manganese, has a hardening effect, rendering the steel hard to tool.

Phosphorus and sulphur, limited to the amounts stated above, are not objectionable.

In *Fig. 9* the upper curve shows what in ordinary practice

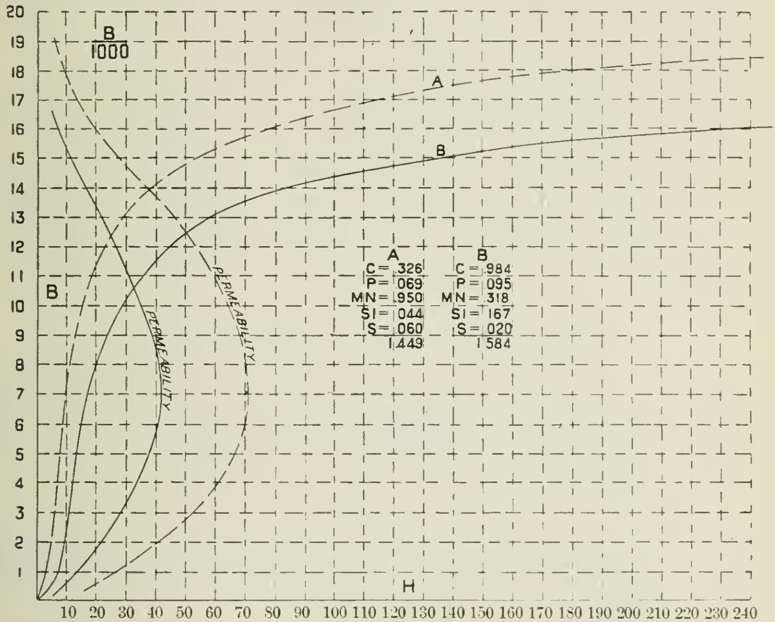


FIG. 10.

is termed good steel, the lower curve shows what is termed poor steel. Corresponding analyses are shown in Tables I and II.

TABLE I.—DATA OF TEN FIRST QUALITY SAMPLES OF CAST STEEL.

	I.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*VII.*	*VIII.*	*IX.*	*X.*	*Average.*
B for H = 15,	12,200	12,000	12,100	12,900	13,000	12,300	13,100	12,100	12,600	13,000	12,500
B for H = 25,	14,100	13,600	13,900	14,400	14,600	13,900	14,500	13,700	14,200	14,500	14,100
B for H = 50,	15,800	15,300	15,600	15,900	16,600	15,600	16,100	15,400	15,800	16,000	15,800
B for H = 75,	16,600	16,200	16,600	16,500	17,600	16,400	17,100	16,300	16,700	16,600	16,700
Carbon, . . .	·240	·267	·294	·180	·290	·250	·200	·230	·170	·180	·230
Phosphorus, .	·071	·052	·074	·047	·037	·093	·047	·100	·089	·047	·057
Silicon, . . .	·200	·236	·202	·120	·036	·230	·170	·160	·150	·120	·195
Manganese, .	·480	·707	·655	·323	·550	·410	·530	·450	·390	·323	·482
Sulphur, . .	·040	·060	·050	·050	·050	·030	·030	·040	·020	·050	·042

TABLE II.—DATA OF TEN SECOND QUALITY SAMPLES OF CAST STEEL.

	I.	*II*	*III.*	*IV.*	*V.*	*VI.*	*VII.*	*VIII.*	*IX.*	*X.*	*Average*
B for H = 15,	10,600	10,600	10,700	9,000	9.300	10,000	10,400	10,000	9,300	11,300	10,120
B for H = 25,	12.700	12,700	13,100	11,200	11,600	12,100	12,500	12,400	11,800	13,500	12,360
B for H = 50,	14.900	14,600	15,100	13,500	13,900	14,300	14,400	14 700	14,100	15,700	14,520
B for H = 75,	15,900	15,600	15,900	14 400	14,900	15.300	15,300	15.700	15,000	16,500	15,450
Carbon, . . .	·250	·280	·195	·333	·337	·366	·409	·318	·702	·380	·357
Phosphorus, .	·087	·076	.028	·059	·045	·151	·063	·107	·084	·066	·077
Silicon, . . .	·210	·210	·683	·292	·302	·476	·444	·203	·409	·550	·378
Manganese, .	·790	·720	·815	·681	·642	·617	·640	1·636	·088	·790	·742
Sulphur, . .	·020	·030	·040	·060	·070	·040	·010	·030	·050	·030	·038

Fig. 10 shows curves and analysis of two different samples of steel showing the effects of combined carbon.

In *Fig. 11* is given similar curves for mitis iron and in Table III corresponding analyses. An inspection of these analyses show they do not furnish a clear indication as to the effect of the various impurities. It will be noticed, however, that in a poor quality there is generally an excess of impurities, this excess of impurities denoting a lack of homogeneity and a greater degree of hardness than in a good steel.

TABLE III.—DATA OF TWELVE SAMPLES OF MITIS.

	I.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*VII.*	*VIII.*	*IX.*	*X.*	*XI.*	*XII.*	*Average.*
B for H = 15,	12,600	14,500	14,500	12,700	13,900	14,200	14,000	10,800	10,000	12,900	12,700	11,800	12,900
B for H = 25,	13,600	15,600	15,700	14.500	15,000	15,700	15,300	12,650	11,900	14,300	14.300	13,400	14,300
B for H = 50,	14,800	16,900	16,700	16,200	16,300	16,800	16,500	14,300	13,900	15,900	16,000	15.000	15.800
B for H = 75,	15,500	17,600	17,500	16,900	17.000	17,400	17,100	15 200	14,800	16,800	16,800	15,700	16,500
Carbon, . .	·065	·105	·106	·125	·136	·212	·214	·216	·235	·241	·242	·260	·180
Phosphorus,	·083	·093	·112	·166	·053	·056	·052	·128	·065	·093	·094	·120	·093
Silicon, . . .	·073	·045	·050	·046	·111	·126	·111	·083	·122	·072	·099	·020	·080
Manganese, .	·112	·108	·099	·120	·191	·405	·401	·167	·107	·248	·253	·140	·196
Sulphur, . .	·150	·050	·050	·050	·030	·040	·040	·010	·030	·030	·030	·030	·045
Aluminum, .	·079	not determined.	·059	·183	·008	·273	not determined.	·152	·055	·120	·119	·080	·113

The effect of annealing on the permeability of cast steel varies considerably, according to the treatment at the foundry. In an ordinary sample annealing seems to increase the permeability for low magnetizations, but for high magnetizations the effect is less marked.

The effect of tempering is to greatly diminish the permeability.

Results of an interesting experiment illustrating the intimate connection between the physical and magnetic properties of steel are shown in *Fig. 12*. Curve 1 shows a

test of sheet steel as received. Curve 2 shows test of same after annealing. Curve 3 shows test of the same sample after being subjected to a pressure of 40,000 pounds per square inch. It will be noticed that the annealing in this case materially increased the permeability, but that the sub-

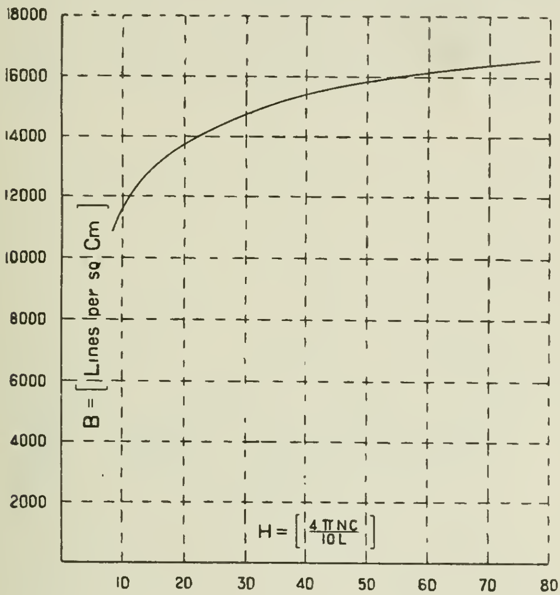


Fig. 11.

jecting of the sample to pressure diminished the permeability below its original value. The analysis of this test is:

$$
\begin{aligned}
C &= \cdot 049 \\
P &= \cdot 117 \\
Mn &= \cdot 369 \\
Si &= \cdot 202 \\
S &= \cdot 1
\end{aligned}
$$

We will next consider the quality of steel that is most suitable for plates of armature cores. These plates in ordinary practice vary from ·014 inch to ·030 inch in thickness; in consequence, steel has to be of very good quality, mechanically, otherwise it would not withstand the rolling process. There is very little difference between the chemical

analysis of the steel that is ordinarily used in these plates and wrought iron. In general, plates made by the steel process show more manganese, and those made by the iron process show more silicon; in fact, these are the clues that serve in practice to identify the processes. Steel to be of the most satisfactory quality must have a minimum tendency to persist in any magnetic state it may have acquired. This may be expressed in other words, by saying that the energy required to overcome the intermolecular

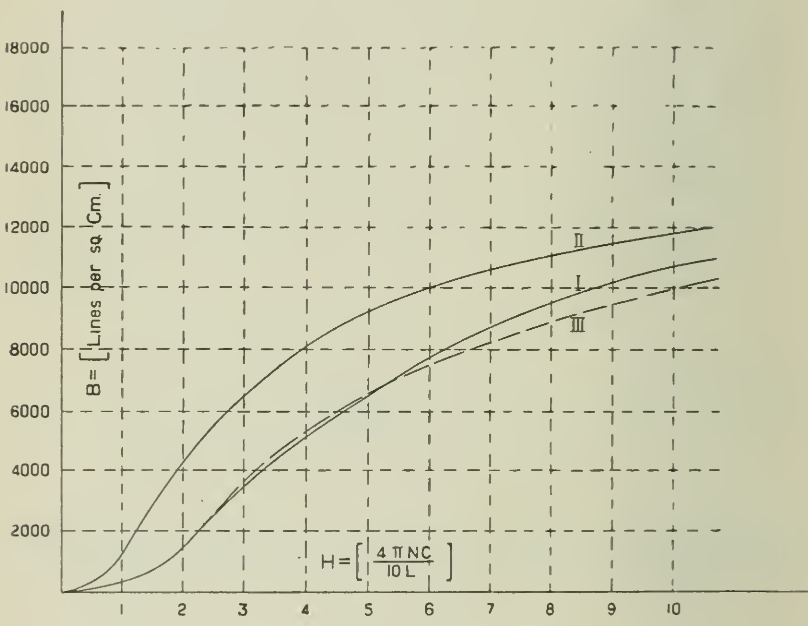


FIG. 12.

friction brought about by changing the direction of magnetization of the iron should be a minimum. This tendency to persist in a formerly acquired magnetic state is termed hysteresis, and the amount of hysteresis is measured by the amount of energy required to completely reverse the direction of magnetization.

In *Fig. 13* are given a number of curves for different cycles, showing how hysteresis varies with the intensity of magnetization in ordinary quality sheet steel.

It is most difficult to determine the effect of the chemical constituents upon the hysteretic loss in sheet iron and steel. This is owing to the fact that with the usual compositions low in silicon, a very slight difference in the annealing will make a disproportionately great difference in the hysteretic loss, and as it is a matter of great difficulty to subject different samples to even approximately similar conditions of annealing, it is hard to illuminate this large

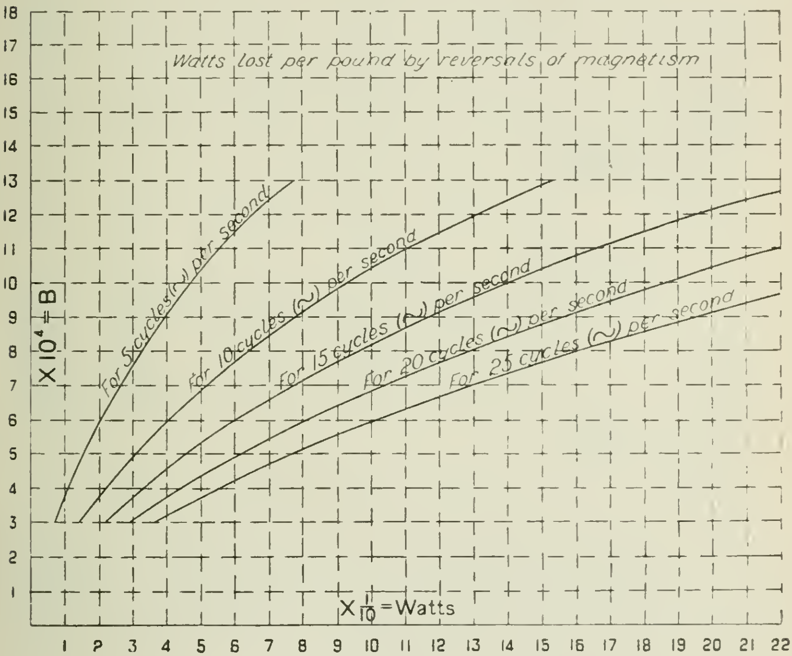


FIG. 13.

variable effect sufficiently accurately to determine at all satisfactorily the residual effects of the chemical constituents.

Silicon in the proportions occurring in sheet iron and steel is not very harmful except that it tends to prevent to a certain extent the improvement that would otherwise result from annealing.

Manganese and sulphur up to a considerable amount (·6 per cent. for manganese, and ·06 per cent. for sulphur) do not increase the hysteretic loss.

From the tests made up to the present time the following conclusions seem warranted. Phosphorus is especially objectionable as regards the hysteretic loss and has more tendency to increase the hysteretic loss than carbon.

Two tables are given below, showing the amount of energy dissipated per cycle, first in six exceptionally good samples, and second in six exceptionally poor samples.

TABLE IV.

	I. per cent.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*Average.*
Carbon,	·076	·085	·072	·086	·095	·078	·082
Phosphorus,	·058	·052	·057	·084	·075	·056	·064
Silicon,	trace	·005	·006	trace	·007	·012	·005
Manganese,	·297	·021	·417	·320	·322	·026	·246
Sulphur,	·060	·030	·030	·040	·030	·010	·033
Ergs per cubic centimeter per cycle at a density of 8,000 lines per square centimeter,	2,800	3,100	2,800	3,000	3,300	3,400	3,070
Material,	sheet iron.		S S	S S	S S	S S	

TABLE V.

	I.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*Average.*
Carbon,	·153	·063	·117	·099	·090	·153	·113
Phosphorus,	·032	·075	·101	·135	·101	·081	·088
Silicon,	·007	·008	·005	·000	·027	·002	·008
Manganese,	·430	·036	·401	·449	·449	·486	·375
Sulphur,	·050	·030	·010	·080	·030	·070	·045
Ergs per cubic centimeter per cycle at a density of 8,000 lines per square centimeter,	8,300	9,000	8,500	8,050	8,000	8,020	8,310
Material,			S I	S I	S S	S S	

The average of Table V shows somewhat larger percentages of all impurities than that of Table IV. But the exceptionally poor results of Table V, as well as the exceptionally good results of Table IV are undoubtedly due largely to the difference in the annealing. Annealing has a tendency to make the structure of the iron more homogeneous, leaving the molecules freer to change their direction. Experiments have been made to show that hysteresis can be lessened from 8,000 ergs per cubic centimeter per cycle to about 2,000 by careful and continuous annealing.

With respect to the use of steel in general for magnetic purposes, it may be stated that the most valuable products are those that are found to be softest and most homogene-

ous. In a given sample any physical change which increases the permeability and correspondingly diminishes the hysteresis. In different samples steel of the highest permeability may not give the best results as to hysteresis; thus a trace of uncombined carbon has a tendency to greatly lessen the permeability, but does not seem to greatly affect the hysteresis.

The most hoped-for improvements in steel are in the making of castings free from blow-holes and surface defects, requiring a minimum of finish, and which are soft and easily machined. Such castings would certainly prove satisfactory from a magnetic standpoint.

In conclusion I wish to express my indebtedness to Mr. H. M. Hobart for the assistance he has rendered in the collection of the data used in this paper.

A PLEA FOR THE STUDY OF ELEMENTARY FORESTRY IN THE LOWER SCHOOLS.

By Edwin J. Houston, Ph.D.

[*A lecture delivered before the Franklin Institute, November 3, 1893.*]

[*Concluded from p. 31.*]

A wide dissemination both of the knowledge of the evils following the removal of the forests, as well as the benefits ensured by their protection is necessary for the public welfare. How shall this much-needed information be given to the general public? How best may these important facts be made matters of common knowledge? I would answer not only by means of suitable literature in books, newspapers, and periodicals generally: not only by means of lectures and addresses, but also, indeed, I believe mainly, by means of proper instruction given to the children of our lower schools.

I would, therefore, urge that elementary forestry be made a study in our lower schools for the following reasons; viz.,

(1) As a matter of public policy, because I believe such study necessary properly to instruct the public through the

children as to the duties it owes the State to insist on the enactment of penal laws for properly protecting the forests in certain sections of the country.

(2) Because I believe that such study can be placed on the curricula of our lower schools without necessitating the introduction of an entirely new study, since it can be made a branch of that basic study of elementary natural science which nearly all agree should form an essential part of the child's early school work.

If the important lesson can thus be given to the child as to the duties it owes to the State in the protection of the forest, not only without interfering with its other studies, but even as a proper and natural expansion of such studies, I feel sure you will agree with me as to the advisability of introducing the study of elementary forestry into the lower schools.

The question naturally arises here, what is meant by the lower schools? Perhaps this title for my lecture is a somewhat misleading one; for, by the lower schools I certainly do not mean anything lower than the schools of a grade intermediate between our primary and grammar grades. I believe the study of elementary forestry can be taken up profitably in schools intermediate in grade to the primary and the grammar, though I believe it could better be taken up in the grammar grades. Of course, it could still better be taken up in the high school or in the colleges or universities; but here the very purpose of the movement would be lost. The main reason for not leaving this study for the schools of the higher grades, arises from the fact that so few of the children ever reach the higher grades, by far the largest proportion numerically leaving school either at the end of the primary or at the end of the intermediate grades. This movement to introduce the study of forestry into the lower schools, being inaugurated mainly for the purpose of teaching this subject to as great a number as possible of the children who are afterwards to become citizens, would thus be rendered ineffectual.

Now, as to the scope of the study of forestry that I would propose for introduction into the schools as low as (say) the

intermediate grades. I should, of course, as I have already stated, make this study of the most elementary character. I wish it to be distinctly understood that I do not advocate the studying of forestry as a formal study necessitating the use of a text-book, unless, indeed, such book be merely as a reader; I would rather make forestry a branch of elementary science (say of geography), or of elementary natural science in general.

I would teach, as far as possible, the general principles underlying the growth of trees and vegetation, the laws regulating the distribution of the sun's heat; the peculiarities attending the evaporation and precipitation of moisture; the general laws of drainage, etc. But it will be noticed that these matters have already been studied in nearly all schools below the grades which we are considering. The children reaching the intermediate grades have already some of these general principles. So far then there is no new study introduced. I would then simply endeavor to show how the presence or absence of a forest covering in any section of country, must necessarily be influential in modifying the distribution not only of the surface drainage, but also of the sun's heat in that section of country, always carefully avoiding debatable questions and ever bearing in mind the age and intelligence of the children to whom the instruction is being given.

That such principles are not too difficult to be properly taught to young children, I think the following synopsis that I would propose for a course of study will abundantly demonstrate. In this synopsis I have carefully avoided all debatable topics, and have introduced only such principles as I believe the child can grasp.

The effects that are generally believed by those who have carefully studied the subject to be produced by the presence of a forest covering are as follows; viz.,

(I) INFLUENCE OF A FOREST COVER ON THE DISTRIBUTION OF THE RAINFALL.

(a) *Tendency of a forest cover to decrease the amount of surface drainage and to increase the amount of subterranean drainage.*

Where a forest cover exists more of the rainfall will reach the lower level by first sinking into the ground and less by running directly off the surface, than if the forest were removed.

The rain which falls on the extended area of a forest, slowly trickles down the trunks of the trees or down the stems or stalks of the undergrowth, and thus finds ready entrance into the ground which is more open and granular than if the trees were removed. The rapidity of surface drainage is decreased by reason of the uneven character of the forest floor, produced by the decaying leaves and vegetable mould, and thus a better opportunity is afforded for the water to sink into the ground.

(b) *Tendency of a forest cover to decrease the amount of evaporation that takes place from the surface of the ground.*

Less of the rainfall will pass directly from the wet earth into the atmosphere, and more will reach a lower level either by surface or subterranean drainage, in a region covered by a forest than in the open, uncovered country.

When the forest cover is removed, more of the rain will pass into the air by evaporation; for, the trees act as a shield partially to prevent this rapid evaporation.

(c) *Tendency of a forest cover to keep the air within the forest somewhat moister than that over the open country.*

Although evaporation is greater in the open country than in the forest, yet the air within a forest is moister than that over the open country, because the removal of the air by winds is less rapid within the forest than it is in the open, uncovered country. According to Fernow, fully half the field evaporation is saved by the presence of the forest. Moreover, during active growth, the forests give off considerable water vapor from their leaves. This amount has been estimated as three times greater than from a water surface. Then, too, in dry weather the trees draw much water towards the surface from the moister, deep-seated strata. All these influences render the air within the forest moister than in the open country.

(II) THE INFLUENCE OF A FOREST COVER ON THE DISTRIBUTION OF THE SUN'S HEAT.

(a) *General tendency of a forest cover to decrease the extremes of temperature both of the soil in which the trees grow and of the air around them.*

Both the soil of the forest and the air within the forest are less subject to rapid heating in summer and rapid cooling in winter than in the open country. This arises from the fact that the covering protects both the soil and the air from direct exposure to the sun's heat, and from direct cooling due to loss by radiation. As a rule, the forest is cooler than the open country in summer, slightly warmer in the spring, and less liable to sudden change throughout the entire year.

(b) *Tendency of the forest cover as a whole to lower the mean yearly temperature both of the soil and of the air within its cover.*

Less of the sun's heat reaches either the ground or the air within the forest than in the open country being absorbed by the leafy canopy forming the upper surface of the covered area. The general effect on both the soil and the air is a cooling one.

(c) *Tendency of a forest cover to delay both the time of early frosts in late autumn and early winter, and the time of excessive high temperatures during the late spring or early summer.*

The general tendency of a forest cover is to decrease the extremes of temperature.

The occurrence of an early frost often causes a great loss to the ripening crops. The delay of a frost by only a week or so may make the difference between a ripened crop and a failure, and may thus mean hundreds of thousands of dollars to the agricultural interests. Late in the summer the air rising from the forests often produce layers of mist over the forest, or in the country near the forest ; these layers act as a covering, which prevents the land from losing its heat as rapidly as it would otherwise. Moreover, a forest may act also as a screen to shield the field to the leeward of a cold air. In times of threatened early frosts the forest may, therefore, in these different ways protect fairly distant areas. The difference in temperature so produced may be

but a small fraction of a degree, but if this prevent the occurrence of a frost, how valuable this small fraction!

(III) INFLUENCE OF A FOREST COVER AS A SHIELD OR SCREEN.

(a) *Action of a forest cover as a protection from hot or cold winds.*

The temperature of the air within a forest cover is more equable than in the open country, not only because the cover protects it from direct heating by the sun, but also because this covering protects the air of the forest from the heating or chilling action of the winds.

(b) *Action of a forest cover as a protection of the soil from the denuding action of the rain.*

When fairly large, rain drops strike the ground in the open country with considerable force, but within the forest cover, the ground is protected from this action, not only by the trees but also by the protective covering of the undergrowth or the carpet of decaying leaves, etc., which accumulates in every forest, if so permitted.

Being bound together to a marked extent by the roots of vegetation, the soil is in this manner prevented from being cut or worn away by the rain.

(IV) INFLUENCE PRODUCED BY DENUDED FOREST AREAS.

(a) *Tendency of the removal of the forest cover to increase the amount of surface drainage and to decrease the amount of subterranean drainage.*

When a forest cover is removed, more of the rainfall reaches a lower level by running directly off the surface and less by sinking into the ground.

The rainfall is no longer able to sink readily into the ground along the trunks of the trees or the stalks of the underbrush. Moreover, no longer finding the soil loose and porous, but compact and hard, it now runs rapidly off the surface.

Besides this, the impact or blow of the rain drops hardens or compacts the soil, and this favoring the drawing up of water from below by capillarity, ensures a further loss by

evaporation at the surface, still further decreasing the amount of subterranean drainage.

(b) *Disturbances in the distribution of the drainage on the reservoirs of springs.*

The removal of the forest cover, tending as it does to decrease the amount of rain that reaches a lower level, by first sinking into the ground, necessarily causes a smaller quantity of water to reach the reservoirs of springs.

With the rapid drainage of the surface waters, and the consequent decrease of the underground drainage, the quantity of water reaching the reservoirs of springs is decreased and their flow necessarily lessened. Instead of being almost unaffected by dry weather their flow rapidly decreases on the approach of drought, and, after a time, may entirely disappear.

(c) *Effects produced by disturbances in the drainage on the quantity of water in the river channels.*

As the removal of the forest covering tends to increase the amount of rain that reaches a lower level by running directly off the surface almost immediately after a severe rainfall, the river channels must begin rapidly to fill, and soon to overflow and so cause floods.

The water that fails to reach the reservoirs of springs runs directly off the surface, and, instead of reaching the river channels by draining underground through the outlets of springs, runs directly into these channels and may thus cause disastrous floods.

(d) *Effects of the disturbance in the drainage, consequent on the removal of the forest cover, on the severity of droughts.*

The removal of the forest cover, tending as it does to decrease the amount of the rainfall that reaches the reservoirs of springs, causes the springs rapidly to dry up shortly after the rain ceases, and, consequently, tends to cause the rivers themselves to dry up, since they are no longer fed by the springs, and the surface water is no longer pouring into them.

The evils caused by too much water in the river channel almost immediately after the rain, are followed by those caused by too little water on the approach of drought. The

rivers completely or partially dry up and the springs fail. Vegetation is thus deprived of its liquid nourishment, the crops fail or the harvest is ruinously decreased both in quantity and quality.

(e) *Effects produced by the removal of the forest cover on the erosion of the surface.*

The removal of the forest cover and the consequent rapid surface drainage of the rainfall permits the removal of the soil, not only on account of the increase in the velocity with which the surface water flows towards a lower level, but also because the soil is now no longer held or cemented together by the roots of the vegetable growth. The soil in which the forests grew is thus lost to the area from which the trees were removed, and, unless such loss is trifling, must needs be replaced before a successful re-forestation or re-planting of the trees can be effected. Moreover, the influence, as far as the river channels are concerned, is not limited to the immediate neighborhood of the forest, but extends far beyond it.

(f) *Effects of the removal of the forest cover on the channels of the rivers whose basins lie in the areas so denuded.*

The soil removed from the river basins, both within the forest areas and in regions beyond these areas, is deposited in all parts of the river channel, where the velocity is sufficiently small, producing bars, mud flats, or shoals in the channel, or partially blocking the river's mouth by the well-known delta formation.

It is especially to be remarked that this influence reaches beyond the area of the forests, to wherever the river flows, viz., often from the mountains or cradles in which the streams are born, to their graves in a lake or ocean; or, not infrequently, from the interior of a continent to its ocean borders.

The damage thus wrought is therefore, far-reaching: the uplands deprived of their soil, the lowlands are contaminated by the miasmatic and other noxious vapors passed into the air from the mud flats, and the navigation of larger streams is often seriously interfered with.

(V) INFLUENCE PRODUCED BY THE PRESENCE OR ABSENCE OF THE FOREST ON THE AMOUNT OF THE RAINFALL.

Since this must, to a certain extent, be regarded as one of the debatable questions in forestry, I would not attempt to discuss it in elementary teaching, except, perhaps, to state that the general concensus of opinion is that the presence of an extended wooded area appears in certain cases to increase somewhat the amount of the rainfall.

It might be well, however, in this connection, to point out the fact that the disturbances in the distribution or the rainfall which unquestionably attend the removal of the forests, are often confounded with disturbances in the quantity of the rainfall. Because destructive droughts and empty river channels follow in the wake of the removal of the forest, the unthinking are apt to ascribe such evils to a decreased rainfall, forgetting the floods in the same river channels which also attended the removal of the forests.

(VI) INFLUENCE PRODUCED BY THE PRESENCE OR ABSENCE OF THE FORESTS ON THE GENERAL CLIMATE OF THE EARTH.

This is also to be regarded as a yet unsettled question, and I would not, therefore, attempt to discuss it in elementary teaching.

I have given in the preceding synopsis of the effects produced both by the presence and by the removal of the forests, a short summary only of the general facts that I believe should be taught in such a discussion of forestry as I should recommend for teaching in our lower schools. Of course, there should be a development of the topics here only generally indicated. I have given this synopsis not only for forming the skeleton of a scheme for elementary study, but also for the purpose of convincing you that the character of the topics to be studied is far from being such as would elude the comprehension of young children. I think you will agree with me that these subjects, with perhaps a few exceptions, are of an exceedingly simple character, and such as could readily be taught. For my own part, I feel quite sure I could teach a class of ordinarily intelligent

children of any grade above the primary, sufficient of the preceding principles to enable them thoroughly to understand the good effects produced by the presence and the evil effects produced by the removal of the forests from extended areas.

As I have already stated, I would not recommend the use of a text-book in such study, unless it be a carefully prepared reader, which might be employed to great advantage. I would rather prepare both as an aid to the teacher and students a series of charts, each containing the outlines of a lesson suitable for the grade of the students employing it.

It is especially to be observed that much of the information required for such teaching of elementary forestry is of the nature of elementary geography, especially of that branch of geography generally known as physical geography. The study I recommend for introduction into the lower schools is not, therefore, properly to be regarded as a new study, but, as I have already remarked, it is rather an extension of geography or of elementary physical science.

Along with the preceding elementary principles relating to the effects produced by the presence or absence of forests, I would give elementary instruction concerning the best methods of re-forestation or tree planting.

The question of tree planting has properly been considered of such importance in this Commonwealth that two days are set aside as Arbor or Tree Planting Days, and I am glad to say that our school authorities have ordered that appropriate exercises shall be conducted in all the public schools on such occasions.

The subject of tree planting is naturally a very attractive one to intelligent children. So, too, is the growth of the tree, or, indeed, of any plant. In the first place, there is the germ or seed from which the tree grows. Then there is the cradle in which the plant after birth is nourished and cared for; such cradle is the soil. Then comes the sunshine and the heatshine that awaken the germ from its long sleep. Then comes the nourishment or food; first the part surrounding the germ and lying inside the seed, and next the greater part lying outside the seed, which the plant obtains from the

soil, or from the atmosphere. Such lessons can be made to the intelligent child more interesting than fairy stories; in fact, they form veritable fairy stories.

I would call the attention of the child to the different character of soils, and to the different ways in which soils are formed. I would show how, in most cases, the formation of soil was slow. How a portion of it, namely, the vegetable mould, was formed by an extremely gradual accumulation of the remains of decaying plants, pointing out how great a loss must ensue to any section of country if, by reason of the removal of its forests or other vegetable covering, the soil should be lost.

Having thus shown the effects both of the presence of the forest and of its removal, I would be especially careful to point out the many uses of the forest. I would show the extent to which the forest crop is necessary to man, especially teaching that man should be free to harvest the crop, explaining that the effort of intelligent forestry is not to prevent man from harvesting the forest crop, but to teach him how to do so intelligently, and how to replant denuded areas or properly to protect their surfaces if it be determined not to replant them.

Where time admits, the causes leading to the removal of the forests and the necessity that exists for such removal over very extended areas might next be discussed. Then, too, I would enumerate the various enemies of the forest; enemies from which the forests should be protected by the enactment of penal laws, viz., the greed of the lumberman, the forest fire, the ravages of winds or avalanches; the devastation by parasitic plants, insects and animals generally.

I have endeavored to show why I believe that the study of elementary forestry should be introduced into our schools in grades as low as the intermediate or grammar grades. I leave it to your judgment whether or not I have made out a good case for such introduction.

THE HISTORY AND MODERN DEVELOPMENT OF THE ART OF INTERCHANGEABLE CONSTRUCTION IN MECHANISM.*

BY W. F. DURFEE.

[*Concluded from p. 54.*]

The art of interchangeable construction was strongly reinforced by the discovery of the method of forging in dies. This idea was but an application of the art of coining cold metal for use as money (which had been known since the time of Darius, 500 years B. C.); to the shaping of metal while hot. The art of forging in dies is believed to have originated in France about the middle of the twelfth century; and numerous examples of "hinges," "grilles" and wrought-iron ornaments of various kinds remain as elegant testimonials of the cultivated taste and wonderful skill of these ancient artists in iron. Forged ornaments, shaped by "dies" (sometimes called "swages"), were common on all the pleasure carriages made in the last century, and it is certain that the wonderful "one-horse shay" would not have been the masterpiece it was if its "step-irons" had not been decorated with "swaged" ornaments.

It seems but a very short step, indeed, from the forging of ornamental iron work in dies, to the forging of the smaller parts of machinery in the same way; but as short as it undoubtedly was, it does not appear that it was taken until the late Albert Eames introduced the practise of forging parts of muskets and pistols in "dies" or "swages," at Chicopee, Mass., in 1842.

One more step forward in the art of forging the parts of interchangeable mechanisms brings us to what is known as "drop forging." This art is believed to be of American origin, and was first used at Harper's Ferry, Md., in the year 1827, in the works of J. H. Hall. An improved form of drop

* A paper read before the Mechanical Section of the Engineering Congress, at the World's Columbian Exposition (August, 1893).

forging machine was made by the late Albert Eames for the Remington Works at Ilion, N. Y., in 1846. From this date the use of the process of drop forging has rapidly increased, and it has been applied to the manufacture of very intricate as well as delicate articles. The Billings & Spencer Company, of Hartford, have for the past twenty-five years turned out annually large numbers of shuttles for sewing machines so nearly exact to size, as to require little work and polishing to render them fit for their intended service. The art of drop forging is also used for producing the heavier parts of bicycles and for an endless variety of forgings in iron, steel and copper; forging of the latter metal having come into use for electrical machinery within the last eight years. So important has the art of drop forging become as a factor in manufacturing, that at the present time no establishment for the manufacture of interchangeable mechanism, of which forgings are a component part, can afford to ignore its advantages. In the making of drop forging, the preparation of the dies is a matter of the first importance, and so high has American skill in this particular appreciated abroad, that from time to time, large numbers of finished dies have been sent from America to foreign countries. The Billings & Spencer Company, of Hartford, Conn., who are pioneers in the art of drop forging, shipped at one time forty-two tons of dies to Prussia, for the making of forgings for the parts of muskets.

The economical production of interchangeability in mechanism, necessitated instruments for rapid and accurate measurement. These were slowly supplied. The invention of the micrometer, by William Gasgoigne, of Yorkshire, England, about the year 1637, at once placed in the hands of science, the power of measuring to a degree of minuteness unknown before. Gasgoigne was killed when thirty-two years of age, at the Battle of Marston Moore, on the 2d of July, 1644, while fighting for his King. The principles of Gasgoine's micrometer consisted in moving two parallel edges or pointers, to or from each other, by means of a screw provided with a divided head. Dr. Robert Hook proposed to use in this micrometer parallel wires or hairs, but, with

such slow, hesitating steps did improvement move in the days of the youth of the micrometer, that it was not until 1755, more than 100 years after its birth, that the first suggestion of the use of spider webs therein was made by Prof. Felice Fontana, of Florence, and it was not until John Troughton's attention was called to the matter by David Rittenhouse, of Philadelphia, that it was carried into practice in 1788; the idea curiously enough reaching England by way of America. There is no certainty that Rittenhouse had ever heard of Professor Fontana's suggestion, but before calling Troughton's attention to the value of the spider lines for micrometers, he had already used them himself in the fixed diaphragm of a transit instrument. Since the application of the spider lines to the micrometer, this instrument has received endless modifications to adapt it to special service, from the hands of some of the ablest scientists and mechanicians of Europe and America. Neither my alloted time nor your patience will permit a description of what has been accomplished in the invention of special types of this instrument; but a brief account of the origin of the micrometer caliper, now so commonly used by the best workmen all over our land, may be of interest. It appears that the first of this form of caliper used in America, was made in the year 1867 in the machine shop of the Bridgeport Brass Company, at Bridgeport, Conn., from sketches furnished by S. R. Wilmot, who at that time was Superintendent of that company. This instrument was made to measure in thousandths of an inch, the thickness of sheet brass then being rolled for the Union Metallic Cartridge Company, to use for the manufacture of cartridges.

The requirements of the late A. C. Hobbs, then the Superintendent of the Cartridge Works, had so narrow limits of variation, that some more accurate means of measurement than the ordinary wire gauge was required to regulate the rolling. This is doubtless the first instance in which common-sense asserted itself successfully against several centuries of rolling mill practice, in determining the thickness of sheet metal, and it deserves to be regarded

as the initial step in the movement that promises ere long to consign all "*wire gauges*" to the tomb of defunct mechanical expedients.

It is also in evidence that a representative of the Brown & Sharpe Manufacturing Company, of Providence, R. I., saw at the Paris Exposition in 1867, an instrument of similar form and purpose, to that made by Mr. Wilmot, save that the French instrument had a revolving scale attached to its screw. This instrument was invented in *1848*, by Jean Laurent Palmer, a machinist of Paris; and was duly patented in France on the 7th of September of that year. The Brown & Sharpe Manufacturing Company commenced the manufacture of this form of "micrometer caliper" in the latter months of 1867, and from the time it was put on the market by them (1868), its use has rapidly extended; but, there is no small amount of humiliating interest in the fact that it was *nineteen years* after the publication of the invention of M. Palmer, in France, before the mechanics of America discovered the value of this very convenient tool.

The discovery by the late Sir Joseph Whitworth, of a way to produce plane surfaces on metal by "scraping," has had a marked influence in increasing the accuracy of work intended to be interchangeable, and so accurate have surfaces been made by the method described, in a paper read by him before the Institute of Mechanical Engineers, at Glasgow, in 1856, that it has been demonstrated that when two such surfaces are placed in contact, that it requires more force to separate them, than the equivalent of the pressure of the atmosphere upon them, thus showing that the surfaces were approaching the condition of actual molecular cohesion.

Thus far I have discoursed of the development of methods and apparatus which have rendered possible the art of interchangeable construction as it is understood to-day: and have had little to say of special industries whose products are representatives of the degree of perfection to which the art has attained.

When the idea of interchangeability was first promulgated, it was advocated with special reference to the manu-

facture of muskets, and it is a common belief that the idea of making the parts of muskets interchangeable originated in America, but the facts of history compel us to say that this view is not correct. Thomas Jefferson, writing from Paris, to John Jay, under date May 30, 1785, says: "An improvement is made here in the construction of muskets, which it may be interesting to Congress to know, should they at any time propose to procure any.

"It consists in the making of every part of them so exactly alike, that what belongs to any one, may be used for every other musket in the magazine.

"The Government here has examined and approved the method, and is establishing a large manufactory for the purpose of putting it into execution.

"As yet the inventor has only completed the lock of the musket on this plan: he will proceed immediately to have the barrel, stock, and other parts executed in the same way. Supposing it might be useful in the United States, I went to the workman. He presented me the parts of fifty locks, taken to pieces, and arranged in compartments. I put several together myself, taking pieces at hazard as they came to hand, and they fitted in the most perfect manner. The advantage of this when arms are out of repair are evident. He effects it by tools of his own contrivance, which, at the same time, abridge the work, so that he thinks he shall be able to furnish the musket two livres cheaper than the common price. But it will be two or three years before he will be able to furnish any quantity. I mention it now, as it may have an influence in the plan for furnishing our magazines with this arm."*

On the twenty-fourth of January, 1786, Mr. Jefferson writes a similar letter to the Governor of Virginia, in which he is even more emphatic in regard to the gun-locks, he has examined, saying that: "I found them to fit interchangeably in the most perfect manner."

In the year 1798 (thirteen years after Jefferson had found that gun-locks were manufactured in France which "inter-

* *The Writings of Thomas Jefferson.* Edited by H. A. Washington. 1853.

changed in the most perfect manner"), Eli Whitney, the inventor of the saw cotton-gin, contracted with the United States to furnish them with 10,000 stand of arms. In regard to this work, his biographer says,* "The object at which he aimed, and which he fully accomplished, was to make the same part of different muskets, as the locks, for example, as much like each other as the successive impressions of a copperplate engraving." This was a very high standard, and Mr. Whitney struggled energetically against all sorts of difficulties, and doubtless realized to some considerable degree, his intention of making the parts of the muskets interchangeable, and is entitled to great credit for the pioneer work in the art of interchangeable construction which he accomplished, and the large measure of success which he achieved in carrying out with the limited resources available in America at the time, the idea which Thomas Jefferson stated thirteen years before the date of Mr. Whitney's contract, was being prosecuted successfully in France.

Looking backward at the art of interchangeable construction as exemplified in the work done at the beginning of the century, and viewing it in the light of the exact requirements of to-day, it is certain that very little of the work done at that time, would pass inspection now; most of the parts of the old muskets would doubtless interchange, but the exactness of the relations of the parts would not be found up to present standards. The demand for such precision was not made, and could not, with the means at command, have been realized if it had been insisted upon. Even the mechanical means of attaining interchangeability in some of the parts of muskets were not invented until 1853.

As a consequence of the pioneer work of Eli Whitney, and the enthusiastic zeal with which the path he blazed through unknown regions, has been followed, widened, and extended by multitudes of ingenious and skilful mechanicians. America has become the great school of the world for all who are seeking instruction in the art of interchangeable construction. As the result of the excellent work on a

* *Memoir of Eli Whitney, Esq.* By Denison Ohmstead. 1886.

small exhibit of rifles by Robins & Lawrence, of Windsor, Vt., at the International Exposition of 1851 in London, the British government sent a commission to America to study the methods of manufacture by which interchangeable construction was attained.

This commission visited Springfield Arsenal and a number of other public and private armories, and as a result they at once ordered a large quantity of American gun-making machinery, and secured the services of a number of American mechanicians to accompany it to England, and there established the Enfield rifle factory, the first in Europe, in which arms were made on the American interchangeable system.

As an illustration of the perfection which this system had attained when the English commission visited Springfield armory, in 1853, Major Ripley, who was then in command there, ordered ten guns manufactured from 1843 to 1853, to be taken apart, the parts indiscriminately mixed, and the ten guns were then successfully assembled by selecting the parts at random from the general mass.

Since the year 1853, American gun-making machinery has been supplied to the governments of England, Spain, Prussia, Sweden, Russia, Denmark and Egypt; and large quantities of American arms and ammunitions have been shipped to all quarters of the world. So manifest were the manifold advantages of the system of interchangeable construction, as applied to the manufacture of arms, that it has been extended to a great variety of other industries in which large numbers of the same kind of product are manufactured: Locks, sewing machines, steam valves, steam engines, hardware and agricultural implements, clocks and watches. The idea of manufacturing watches by the interchangeable plan is distinctly American, and was first carried into effect on a large scale at Waltham, Mass., in 1854. Since that date watch factories have increased and multiplied in the land and foreign nations have been compelled by American competition to adopt the idea which is the crowning triumph of the American system of interchangeable construction.

In the foregoing outline of the development of those

arts which are distinctly tributary to the art of interchangeable construction, I have endeavored to show that the idea of interchangeability in the construction of mechanism is of no recent origin: that, in fact, if not in name, the commencement of its practical development was coeval with the satisfaction of the most primitive of the artificial demands of man upon the materials of the world, in which he found himself placed: that as mankind increased, and multiplied his requirements of nature; the elements from which to create the art of interchangeable construction were necessarily augmented by the discovery of new methods and the invention of apparatus for their utilization: that this process of mental demand and material supply, changed gradually from the simple and easy, to the complex and difficult: but, nevertheless, every demand within what we have been irreverently taught to call the laws of nature, has been successfully met by the crystallization in its work of enough of the immortal soul of each succeeding generation, to enable the world of our day to enjoy the usufruct of the labors of all time past, and to rejoice in the practical perfection to which the art of interchangeable construction has attained.

Contemplating the magnitude of past achievements; realizing the vast power which the concentration of the inspired thought and best work of all ages have placed at our disposal, perceiving as "through a glass darkly" a suggestion of the manifold glories of that future which will be the living present of some unknown generation; we seem to see science in command of a grand ship called *Art*, fully rigged, manned and equipped for a voyage of unknown length; its prow pointed westward, as, with adventurous keel, flowing sails, and a crowning glory of flags, pennons and streamers, it speeds over the uncharted waters of the ocean of time towards undiscovered shores. As we view the picture and reflect upon the persistent faith that has guided the noble vessel to the discovery of fair islands and grand continents in time past—the mind naturally reverts to the voyage of that great discoverer, in whose name we have erected these temples, and invited all lands to do him

honor by offerings of gold and silver, frankincense and myrrh.

It is by such persistence as his, in following the directing compass of an o'er mastering faith, that science and its argosy will make discoveries of new lands under skies and stars to us unknown. On such a voyage science will permit of art no suggestion of turning, and when doubt shakes its skeptical head, and fear asks timorous questions, the reply of science will be as sternly decisive as was that of Columbus, when

> "Behind him lay the gray Azores,
> Behind, the gates of Hercules,
> Before him only ghosts of shores;
> Before him only shoreless seas,
> The good mate said: 'What shall I say
> If we sight naught but seas at dawn,'
> Why you shall say at break of day?
> 'Sail on—sail on—sail on—and on.'"*

COMMENTS ON THE DETERMINATION OF PHOSPHORIC ACID BY TITRATION OF THE "YELLOW PRECIPITATE" AS DESCRIBED BY MR. HENRY PEMBERTON, JR.

By W. J. Williams, F.I.C., F.C.S., etc.

[*Read at the stated meeting of the Section, held November 21, 1893.*]

On September 19, 1893, at a meeting of the Chemical Section of the Franklin Institute, I heard with great interest Mr. Henry Pemberton's, Jr., paper on the determination of phosphoric acid by titration of the yellow precipitate with standard alkali.

For some time I have been seeking a *reliable* volumetric method for the determination of phosphoric acid. The well-known uranium nitrate method is sufficiently accurate for most purposes on an aqueous solution of phosphoric acid, but is entirely unreliable if the phosphatic material is dissolved in mineral acids or even in acetic acid.

* Joaquin Miller.

After some conversation with Mr. Pemberton on the subject, subsequent to hearing his paper, he very kindly sent me by letter some valuable hints and instructions on the details of the process, with the help of which I began my investigation.

The first trials were made on ordinary mixed fertilizers, containing ammoniates and potash salts, and the result showed an almost exact agreement with previous results obtained by the usual gravimetric method.

	Phosphoric Acid by Pemberton's Vol. Method. Per Cent.	*Phosphoric Acid by Gravimetric Method. Per Cent.*	*Difference Per Cent.*
Ammoniated phosphate, ...	15·475	15·480	0·005
Acid phosphate with ammonia and potash,	13·175	12·980	0·195
Acid phosphate with ammonia and potash,	13·730	13·820	0·090
Acid phosphate with ammonia and potash,	11·100	11·000	0·100

These I consider to be highly satisfactory results, and such as justified further investigation as to the reliability of the method on substances rich in phosphoric acid, such as Florida phosphate rocks, and on the other extreme of substances low in phosphoric acid, such as the "insolubles" in a well-made fertilizer.

High-grade Acid Phosphate.—Working on 0·2 gram for the "total phosphoric acid," and on 0·5 gram for the phosphoric acid "insoluble in ammonium citrate," I found

	By Volumetric Method.	*By Gravimetric.*	*Difference.*
"Total" No. 1, ...	16·830	16·57	0 26
No. 2, ...	16·750	16·89	0·14
"Insolubles" No. 1, ...	0·24	0·32	0·08
No. 2, ...	0·36	0·32	0·04

On ordinary mixed fertilizers.—

"Totals" No. 1, ...	15·28	14·78	0·50
No. 2, ...	14·60	14·14	0·46
No. 3, ...	12·29	11·45	0·84
No. 4, ...	13·83	13·43	0·40
"Insolubles" No. 1, ...	1·90	1·79	0·11
No. 2, ...	4·35	4·22	0·13
No. 3, ...	2·06	2·17	0·11
No. 4, ...	1·82	1·79	0·03

Here, again, I consider the results highly satisfactory.

I next worked on high grade Florida phosphate rocks, using in each case 0·1 gram of substance. To insure a fair sample, however, I first dissolved five grams of rocks in hydrochloric acid, and made up to 250 cubic centimeters and mixed thoroughly by shaking and decantation. Of this solution I took fifty cubic centimeters equal to one gram of rock, diluted to 250 cubic centimeters, and again mixed thoroughly by shaking and decantation. I then took twenty-five cubic centimeters of this second dilution equal to 0·1 gram rock, brought it to alkalinity with ammonia, and acidified with nitric acid, adding a little ammonium nitrate.

	By Volumetric Method.	*By Gravimetric.*	*Difference.*
Florida rock No. 1, ...	32·33	33·00	0·67
No. 2, ...	30·66	30·89	0·29
No. 3, ...	31·55	31·54	0·01
No. 4, ...	31·37	31·34	0·03
No. 5, ...	33·17	33·33	0·16
No. 6, ...	33·24	33·14	0·10

The greatest variation is in No. 1, where it reaches 0·67 per cent., but this is small compared with the variation in results from different analysts. For instance, No. 3 was analyzed by four chemists of repute, and the results were 31·54 per cent., 31·61 per cent., 31·86 per cent. and 34·56 per cent. The chemist who reported 34·56 per cent. was requested to revise his figures and reported the second time 34·44 per cent. These show a greater divergence from the results of the three first analysts than is found in the case of No. 1.

I think, therefore, that Mr. Pemberton's method followed carefully according to his instructions is entirely reliable, for high grade rocks, for plain acid phosphates and for mixed fertilizers, in the hands of careful and competent analysts. But with careless or unskilful manipulation the chances of serious error are very great. For instance, incomplete washing of the yellow precipitate would lead to very serious errors and misleading results but in careful hands the method is accurate and reliable.

WILMINGTON, DEL., November 21, 1893.

COMPARISON OF PEMBERTON'S METHOD OF PHOSPHORIC ACID DETERMINATION WITH THE OFFICIAL METHOD.

BY FRANCIS BERGAMI.

[*Read at the stated meeting of the Chemical Section, December 19, 1893.*]

By the kindness of Dr. Terne, I came into the possession of a copy of Mr. Pemberton's paper, on "Phosphoric Acid Determination." The results shown therein indicate such a surprising accuracy of the method that Dr. Terne requested me to start an investigation at once, as it would be of the highest importance in our work to find a more rapid (and at the same time, equally accurate) process of phosphoric acid determination than the official method. As my spare time is very limited, I have extended my tests only to such materials as just at present enter our laboratory for examination. These materials consist mostly of ammoniated and mixed phosphates.

The results of all the tests made up to this time are given in the following table:

PHOSPHORIC ACID.

Sample.	Official Method.	Pemberton Method.	Difference.
(1) Ammoniated phosphate,	11·84	11·68	0·16
	—	11·77	0·07
(2) Ammoniated phosphate,	13·20	13·05	0·15
	—	13·14	0·06
(3) Ammoniated phosphate,	8·80	8·68	0·12
(4) Ammoniated phosphate,	8·74	8·74	—
(5) Dissolved bone-black,	20·68	20·56	0·12
(6) Ammoniated phosphate,	—	10·93	0·03
(6) Water-soluble, phosphoric acid,	10·96	10·84	0·12
(7) Ammoniated phosphate,	12·48	12·35	0·13
(8) Dissolved bone-black, not identical with No. 5,	20·68	20·55	0·13
(9) Acidulated S. C. Rock:			
Total phosphoric acid,	15·52	15·34	0·18
Insoluble phosphoric acid,	1·72	1·68	0·04
Available phosphoric acid,	13·80	13·66	0·14
(10) Ammoniated phosphate,	12·32	12·17	0·15
(11) Ammoniated phosphate,	—	—	—
(11) Water-soluble, phosphoric acid,	10·56	10·47	0·09
(12) Acidulated S. C. Rock:			
Total phosphoric acid,	15·29	15·16	0·13
Insoluble phosphoric acid,	2·56	2·49	0·07
Available phosphoric acid,	12·73	12·67	0·06
(13) Refuse bone-black,	34·40	34·03	0·37
	—	33·94	0·46
	—	34·03	0·37
(14) South Carolina rock,	27·66	27·34	0·32
(15) Florida rock,	32·24	31·94	0·30

In reviewing all the results, it can be seen that, on the average, the Pemberton process gives slightly lower results than the official method. Assuming my work to be as free from individual error as careful work can be, there are only two explanations for the differences: either the results of the official method are a little too high, or those of the Pemberton method are a little too low. I feel very much inclined to accept the first explanation, for the following reason:

It has been repeatedly stated by different chemists that it is hardly possible to obtain by one precipitation a precipitate of ammonium-magnesium phosphate absolutely free from magnesium oxide, and it has been recommended to dissolve the precipitate again and re-precipitate it with ammonia.

Dr. N. von Lorenz has only lately published his investigation in regard to this source of error in the official method (*Fresenius Zeitschrift*, 1893, p. 64). He shows that addition of about two per cent. of citric acid to the solution of the phosphomolybdate in ammonia will prevent any contamination by magnesium oxide.

When I had obtained the results on Sample No. 13, a refuse bone-black, I found the difference between the official test and even the highest result of the Pemberton method, namely, 0·37 per cent., too high to be passed without a closer consideration. In this case, I had accidentally omitted the neutralization of the ammoniacal solution of the phosphomolybdate by hydrochloric acid. Therefore, the idea struck me that this neglect might be the cause of the too high result, and I concluded to repeat the test twice with addition of citric acid, as recommended by Dr. von Lorenz.

The results thus obtained were 34·08 per cent. and 34·16 per cent. against 34·03 per cent. and 33·94 per cent. by Pemberton method and 34·40 per cent. by official method without neutralization. In former years, I had always precipitated without previous neutralization of the ammonia solution, but as I have lately followed strictly the official way and neutralized, I thought surely that the omission of

neutralization was the cause of the high result. The smaller differences in all previous tests could easily be explained as individual working errors, but when I obtained the results in Samples 14 and 15, I was a little astonished.

In these cases, I was sure of no neglect on my side; the official way was carefully carried out as in all other samples, and I had made the solutions of the yellow precipitate as nearly neutral as possible. Still, the differences between both methods were 0·30 per cent. and 0·32 per cent., respectively.

I always wash the ammonium-magnesium phosphate until the filtrate shows no chlorine reaction, so that the source of error arising from incomplete washing is absolutely excluded, and I am, therefore, at a loss to find any other explanation for the differences than that, even in nearly neutralized solutions, a small amount of magnesium oxide is thrown down, together with the ammonium-magnesium phosphate, and renders the results of the official method too high. Naturally, the error will show itself more in high-grade phosphates than in those of lower percentage.

In calculating the results, I used the figures obtained by Mr. Pemberton, which are based upon the fact that twenty-three molecules of alkali are necessary to neutralize one molecule of ammonium phosphomolybdate. In establishing this fact, Mr. Pemberton precipitates a solution of di-sodic hydric phosphate by magnesium mixture, but he obtains a precipitate absolutely free from magnesium oxide by taking the precaution to dissolve the first precipitate again and re-precipitate with ammonia.

In this way he eliminates the above-stated error in the official method.

If, in establishing the relation between the phosphoric acid in the yellow precipitate and the standard alkali solution, the ammonium-magnesium phosphate were weighed directly after the first precipitation, I feel almost sure the figures thus obtained would be higher, and that results in analyses calculated on those figures would not show such large differences from the official method, as they would involve the same source of error.

In regard to the execution of the Pemberton method, I should like to state the following:

Extremely great care must be taken in washing the yellow precipitate until free from acid. Testing with delicate litmus paper should never be omitted. In regard to rapidity, I found it of some advantage to introduce a little change in Mr. Pemberton's mode of procedure.

To the twenty-five cubic centimeters of acid solution, which is always obtained in the same way (one grain substance thirty-five cubic centimeters nitric acid and five cubic centimeters of hydrochloric acid), I add at once ten cubic centimeters of strong ammonia (specific gravity 0·90), and, after a little stirring, fifteen cubic centimeters of nitric acid (specific gravity 1·42).

This operation secures about the same conditions for all tests, and produces at the same time a temperature of 75° to 80° C., which reduces the time required for heating to boiling point to a minimum.

The method is absolutely free from all difficult manipulations, and the only inconvenience I experienced with it occurred in such samples as gave dark colored acid solutions.

A considerable part of the coloring matter enters the precipitate and imparts to the solution in alkali a brownish color.

This renders the titration a little difficult, and may, in some cases, give rise to uncertainty and error. A previous ignition of the sample or treating with concentrated sulphuric acid would overcome this difficulty. Whether in the case of solution in sulphuric acid, a larger amount of nitrate of ammonia and a longer allowance of time for complete precipitation would be necessary, is still an open question and needs investigation.

Mr. Pemberton recommends a standard alkali solution, which is free from carbonic acid. I have found that in the determination of nitrogen and ammonia a solution with a small amount of carbonates works just as well, as if free from the same, provided phenolphthalein and cochineal are used as indicators for standardization and analysis,

respectively. Both indicators show absolutely sharp end reactions, even if a small amount of carbonates is present. Curious of seeing if carbonic acid would have any detrimental effect in this special case, I repeated some of the tests with an old soda solution, containing some carbonates, with the following results :

Sample.	*1*	*4*	*5*	*12*	*15*
Alkali with CO_2, ...	11·68	8·69	20·47	15·07	31·94
Alkali without CO_2, ...	11·77 11·68	8·74	20·56	15·16	31·94

The close agreement of the different results seems to show that the precipitation of the carbonic acid is an unnecessary precaution.

I do not consider the number of tests made sufficient to prove the absolute infallibility of the Pemberton method, but I think that my work shows at least the probability of obtaining fair results by the same.

The results obtained by Mr. Pemberton and myself should be encouraging enough for any chemist employed in the control of fertilizers, to make a careful study of the method, with the hope of producing an absolute proof of accuracy, which would justify the abandonment of the old, tedious and time-wasting procedure of the official method.

NORMAL CHLORINE IN SPRING WATERS NEAR PHILADELPHIA.

BY REUBEN HAINES.

[*Read at the stated meeting of the Section, held December 19, 1893.*]

The term "normal chlorine" is used to designate the amount of chlorine naturally existing in waters that are entirely free from all contaminating influences arising from the life and occupations of man.

Not only are waters directly polluted by this means to be excluded, but also those in which the ground water within their drainage areas has been contaminated. It is necessary, therefore, to obtain the water from near its source and to ascertain that within its watershed there exists nothing likely to affect the chemical character of the water. In a very sparsely inhabited region comprising large tracts of forests and uncultivated land such normal waters would not be difficult to find. It is quite otherwise in fertile agricultural districts in the vicinity of cities and towns.

It appears probable that in most instances the natural or normal chlorine of a particular locality will be found a tolerably constant average, although wide variations are found occasionally in single cases. This has been found true in Massachusetts, where this matter has been under investigation for several years.

As chlorine is one of the most important factors in water analysis for determining the potability of a water and, by reason of its permanence in the form of sodium chloride, is well adapted for the relative measurement of pollution, it is desirable to know the amount which is normal for a particular locality.

It should be stated, however, that the question of potability is not necessarily considered in the selection of these normal waters Thus many swamp waters although very highly colored and containing large amounts of vegetable matter are quite suitable for this purpose. While on the other hand many spring waters which receive ground water

draining from farm-land are sufficiently pure for domestic use, but are for this reason, viz:—the character of the ground water—not to be classed as normal waters.

Special geological features of rock or soil, however, may greatly affect the chlorine content of waters in certain districts so far as to render the determination of chlorine of little value for this purpose. In the vicinity of the sea-coast a considerable increase in chlorine is to be expected, which, except in immediate proximity to salt marshes and within the line of highest tides, is probably due to salt spray carried inland by winds and precipitated with the rain.

Investigations in Massachusetts (*Report of State Board of Health on Examination of Water Supplies and Inland Waters*, 1890) have shown that the normal chlorine decreases in quite regular series from the coast to the central part of the State. Normal waters near the coast contain about 0·65 part chlorine per 100,000, and in the western part of the State less than 0·10 part. Lines called "isochlors" are drawn on a map of the State, connecting localities having equal amounts of normal chlorine, and these "isochlors" have a general parallelism to the coast line. It appears reasonable to attribute the gradual decrease of normal chlorine to the diminishing influence of sea-air.

From some recent investigations I have made, I believe, a somewhat similar series for normal chlorine can be found for New Jersey and Eastern Pennsylvania. In the present paper, the vicinity of Philadelphia, west of the Delaware River, is alone under consideration. It has, however, been quite difficult to find sources of water in this district which would reasonably satisfy the necessary conditions. Springs on a wooded hillside were mostly selected.

Ten springs, of which twenty-one samples were taken at different times during the year 1893, were found to be available for the purpose and were distributed as follows:

Five springs located on or near the line of the Philadelphia and Newtown Railroad, of which eight samples were taken. Four springs in Chester County, of which there were six samples. One spring on the Wissahickon Creek, Fairmount Park, seven samples taken almost monthly, from April to October.

The results are given as follows, stated in parts per 100,000:

NEWTOWN RAILROAD FROM HARPER'S TO PAPER MILL STATION.

Number of Spring.	*I.*	*II.*	*III.*	*IV.*	*V.*
First sample, ...	·27	·26	·24	·27	·23
Second sample, ...	—	·283	·245	·256	—
Average, ...	·27	·271	·242	·263	·23

CHESTER COUNTY, PA.

Location.	*Cedar Hollow.*	*White Horse Road.*	*Daylesford.*	*Malvern.*
First sample, ...	·210	·190	·170	·240
Second sample, ...	·180	—	·256	—*
Average, ...	·195	·190	·213	·240

* A second sample of this spring, taken five months after the first, was rejected, because a large increase in nitrates, as well as increase in chlorine, showed some pollution to have taken place between these periods. The amount of nitrates in the first sample, collected May 30th, was ·072 parts per 100,000.

WISSAHICKON PARK DRIVE, SPRING ABOUT 400 YARDS ABOVE RITTENHOUSE LANE.

Seven samples collected from April 12 to October 9, 1893:

Number of Sample.	*I.*	*II.*	*III.*	*IV.*	*V.*	*VI.*	*VII.*
Chlorine, . . .	·16	·15	·22	·22	·214	·183	·207

Average of these seven samples, ... ·193

In four of these samples the nitrates were determined, giving a maximum of ·10, minimum ·08 and average ·087 parts per 100,000. A determination of ammonia gave no free ammonia and an exceedingly small amount of albuminoid ammonia.

The average chlorine for the series is ·231 parts per 100,000.

It is probable that the results from the spring at Cedar Hollow and the one on the Wissahickon represent most nearly the true normal, since three of the others are possibly influenced by the cultivation of land or by pasturage in their vicinity. The spring at Cedar Hollow gave only faint traces of nitrates in 100 cubic centimeters of water. The condition and environment of this spring were very good. It flows rapidly from the base of a steep hill covered with dense

woods. Of the springs near the Newtown Railroad, the second gave nitrogen in the form of nitrates ·05 parts per 100,000, and the fifth no nitrates.

It is probable, therefore, that the normal chlorine for the vicinity of Philadelphia approximates closely to ·20 parts per 100,000, and presumably rather under than over this amount. Additional analysis of these and other springs are desirable in order to fix the limit more definitely.

The chlorine was determined by the usual volumetric method with silver nitrate and potassium chromate, but with the improvements and corrections described by Hazen (*Amer. Chem. Jour.*, xi, 409). As this improved method may not be familiar, except to those making similar investigations, it may be briefly stated here as follows: 200–250 cubic centimeters of the water to which are added fifteen to twenty milligrams sodium carbonate are evaporated in a porcelain dish to about twenty-five cubic centimeters. Wash down sides of dish with distilled water, using a rubber, until the volume approximates fifty cubic centimeters. When cold, add one cubic centimeter potassium chromate solution containing sixty milligrams chromate per cubic centimeter. Titrate with silver solution equivalent to 0·5 milligram chlorine per cubic centimeter until a faint permanent tint is visible. From the result of titration deduct a correction for volume represented by the formula

$$X = \cdot 003\ V + \cdot 02$$

in which V is the volume of the liquid in cubic centimeters at the end of the titration. The silver nitrate solution is also corrected previously in making up the solution by the addition of one per cent. of the theoretical weight of silver nitrate required; or standardize with sodium chloride solution and apply the above correction for volume, which will give the same strength of solution. In colored waters from swamps or peaty waters the coloring matter is, previously to evaporation precipitated by alumina hydrate, or by aluminum sulphate and sodium carbonate. The solid residue in a platinum dish after ignition by Drown's radiator may also be used for the determination of chlorine, if pre-

vious to evaporation, fifteen to twenty milligrams of sodium carbonate have been added to the water. I have found duplicates to agree very exactly when using this residue after ignition and have found close agreement between all three methods of getting rid of the vegetable coloring matter in natural waters, as described by Hazen. When using aluminum sulphate it is best to perform the titration with silver nitrate by gaslight.

A CONTRIBUTION TO PEMBERTON'S VOLUMETRIC METHOD FOR PHOSPHORIC ACID DETERMINATION.

BY DR BRUNO TERNE.

[*Read at the stated meeting of the Section, held December 19, 1893.*]

On September 19, 1893, Mr. Henry Pemberton, Jr., presented to the Section, a paper on the "Determination of Phosphoric Acid by the Filtration of the Yellow Precipitate with Standard Alkali."

The results obtained by Mr. Pemberton were such, that it appeared to us, at once, the results of this investigation should be taken up by the chemists interested in the determination of phosphoric acid.

At my request, Mr. Francis Bergami, for the last seven years in charge of the analytical control work of the factory of the Baugh & Sons Company, undertook to make a comparison of the Pemberton method with the official gravimetric method.

Mr. Bergami has made such comparison in fifteen different samples. The first twelve samples represent market products of the fertilizer trade; the last three samples, of raw material for the manufacture of the first.

The highest difference between the two methods, in the first twelve samples, is 0·16 per cent.

If you take up my paper read before the Section, October 18, 1892, pp. 9 to 12, and compare the differences which the official chemists have made on the test sample, you will find

that the differences between the official and the Pemberton method, as obtained by Mr. Bergami, are insignificant.

In the last report issued by the Agricultural Department, of the meeting held in Chicago, August 24 to 26, 1893 (*Bulletin* 38), we find on p. 8, determinations of citrate-insoluble phosphoric acid made by seventeen different chemists, with results of:

Highest. *Per Cent.*	*Lowest.* *Per Cent.*	*Differences.* *Per Cent.*
1·69	1·33	0·36
2·11	1·03	1·08

while Mr. Bergami, in Samples 9 and 12 in the citrate-insoluble phosphoric acid between the official and the Pemberton method, found only differences of 0·04 and 0·07 per cent.

Taking the results of the last three samples with high percentage of phosphoric acid, the highest difference obtained between the two methods, is 0·46 per cent.

Compare this, with the results of the test samples in 1892 for total phosphoric acid by the official method, and you find recorded 0·46 per cent., 1·28 per cent., 1·50 per cent., 1·45 per cent.

While the Samples 13, 14 and 15 of Mr. Bergami show, as the highest, 0·46 per cent., the last official record we have on total phosphoric acid, gives the same figure, as the lowest difference.

The volumetric method, as proposed by Mr. Pemberton, is, in my judgment, as reliable as the official method, and, if anything, more correct in the results.

A great advantage for a laboratory, is the time-saving of this method, without any loss of accuracy.

The work, that Mr. Bergami lays before you has been done with the utmost care and critical observation of all possible shortcomings of the new method.

I am so satisfied with the results obtained, that I do not hesitate a moment to adopt the Pemberton volumetric method for the control of our factory work, though samples of shipments must be treated according to the adopted rules of the association.

This volumetric method of determining phosphoric acid is, to my mind, of such value to all chemists interested

in phosphoric acid determination, and principally to the station chemists and fertilizer manufacturers, that a united effort should be made to push the adoption of the same, at least as an alternate method, before the Association of Official Agricultural Chemists.

I know that Mr. Williams, of Walton Whann & Co., at the next meeting, as indicated in the communication he sent to the Section, will join in this movement.

I shall endeavor to bring this matter prominently before the next meeting of the association, and in the meantime I am trying to interest the leading members of the association in the very excellent method of our fellow-member, Mr. Pemberton.

THE THEORY AND DESIGN OF THE CLOSED-COIL CONSTANT CURRENT DYNAMO.

BY HENRY S. CARHART.

[*A lecture delivered before the Electrical Section, December 26, 1893.*]

Constant current dynamos for arc lighting have been in practical use for the past fifteen years. Most of the public lighting by arc light service has been done with dynamos of the open-coil type. They secured the field at an early day in the development of this branch of electrical industry through the inventive genius of Mr. Charles F. Brush and the splendid ability of his business associates. This success was repeated a little later by the equally brilliant achievements of Professors Thomson and Houston and the phenomenal management of the company formed to exploit their patents. Aside from any question of inferiority, it is therefore easy to see why the closed-coil dynamo for constant currents has remained so long in the background. It has not received the attention to which it is justly entitled, and has not been investigated with the thoroughness and skill which it merits. It is not my purpose to draw any comparisons whatever between open- and closed-coil armatures. The former is entitled to that consideration which long-con-

tinued and satisfactory service in public and private illumination has earned for it. But the latter is making its way into public favor, and it has certain peculiarities which make it an interesting subject for study. If I were to draw attention in this paper to comparisons between dynamos of different types, it would be between those for constant potential and those designed for constant current, both with closed-coil armatures. For in almost every particular the latter is diametrically opposite to the former. The one is designed to give a constant potential; the other a constant current. One is shunt or compound wound; the other series wound. In the one the resistance of the armature is as low as possible in comparison with the field; in the other the armature resistance is relatively large compared with the field. The one has a sensitive field and is worked below the saturation point; the other should have a stable field which is worked well up on the saturation part of the curve of magnetization. Ideally the characteristic of the one is a horizontal line; that of the other a vertical line. In the constant potential machine the brushes are set only slightly in advance of the theoretical neutral line or plane; in the constant current dynamo the brushes may be at any point on the commutator according to the load, while the neutral plane remains fixed. When the load decreases with the one the brushes if moved at all are rocked backward for sparkless commutation; when the load decreases with the other the brushes are rocked forward for minimum sparking or even sparkless commutation and constancy of current. When the load increases on the one it governs by an increase of induction from an increasing field; when the load increases on the other it governs by decreasing the counter electro-motive force in the coils between the brushes and the neutral plane. In the one armature reaction is purposely reduced to the smallest dimensions; in the other it is purposely made of considerable dimensions. In these comparisons it is assumed that the speed is constant in both cases. If some of these statements are not self-evident, they will be supported, I hope, by subsequent portions of this paper.

THE NEUTRAL PLANE INDEPENDENT OF THE PLANE OF COMMUTATION.

By neutral plane is meant a plane passing through the axis of the armature and so situated with reference to the poles of the field magnet, that when a coil of the revolving armature is carried across it the electro-motive force generated changes direction. This plane intersects the armature in a straight line, but it may broaden out more or less into a surface of small lateral dimensions.

The plane of commutation is a plane passing through the armature axis and the points of contact of the brushes on the commutator. It is the plane joining the poles of the armature considered as an electro-magnet. This latter plane of course shifts with the brushes, since the poles of the armature are the points at which the current enters and leaves the armature, and these are necessarily the points or surfaces of contact of the brushes with the commutator, assuming that the connections from the armature to the commutator run directly out parallel to the shaft. To state the proposition now under discussion in the form of a question, does the neutral plane shift when the brushes are shifted forward or backward? If we were to make answer from the assumption that the resultant of two impressed magnetizations or magneto-motive forces may be obtained in the same manner as the resultant of two forces by means of the triangle of forces, we should probably conclude that the neutral plane rotates forward with a forward movement of the brushes. But experiment along several different lines shows that this conclusion is in error. If we were to apply to the solution of this problem the principles derived from constant potential machines we should be forced to the conclusion that, to maintain sparkless commutation at the brushes, the lead of the brushes beyond the neutral plane should be constant, since the current remains constant; and therefore that any attempt to govern for constant current by rocking the brushes must be attended by destructive sparking, unless at the same time the field is greatly modified. But these conclusions are also erroneous.

We must therefore first establish the facts and then make a theory to fit them.

The fixed position of the neutral plane I have determined on a ten-light machine in two different ways.

First Method.—Four turns of No. 16 silk-covered magnet wire were wound around the armature ring as an exploring coil. One end of this coil was soldered to a copper band or ring fastened on the commutator and insulated from it by several thicknesses of mica. The other end was soldered to a piece of brass let into a fibre collar placed round the commutator. One extra brush was fastened to one of the main brush holders and rested on the copper band. The other extra brush rested on the fibre collar and could be attached to any point of a circular scale made concentric with the commutator. A twisted cord ran from these two brushes to a telephone at some distance. When the dynamo was running the movable brush, which rested on the fibre and made contact with the brass strip every revolution, was moved round the circle till a minimum sound was heard in the telephone. The exploring coil was then on the neutral plane at the instant when the brush made contact with the strip. Motion of the brush either way caused the sound to increase in loudness. The position of the exploring coil for minimum sound was found to be about 5° in advance of the normal plane intermediate between the pole pieces; and its position did not change from full load to no load as far as could be detected by this method.

Second Method.—To the brush holders was attached an insulating ring slotted on the periphery at every 10° on a milling machine. It was made as nearly concentric with the commutator as possible. A third brush holder was placed in the successive slots, and the potential difference between it and one main brush was measured in its several positions. These measurements gave the integrated potential difference between the main brush and successive points on the commutator all the way round the circle and back to the starting point. This was done with no load or nearly short-circuit, with a load equivalent to three lamps,

and finally with a load equivalent to nine lamps, the current being ten ampères in each case. The results in the first two cases are plotted round a circle in *Fig. 1.* Positive values, or those in which the potential of the third brush was higher than that of the main positive brush, are set off outside the circle in the upper part of the figure; while nega-

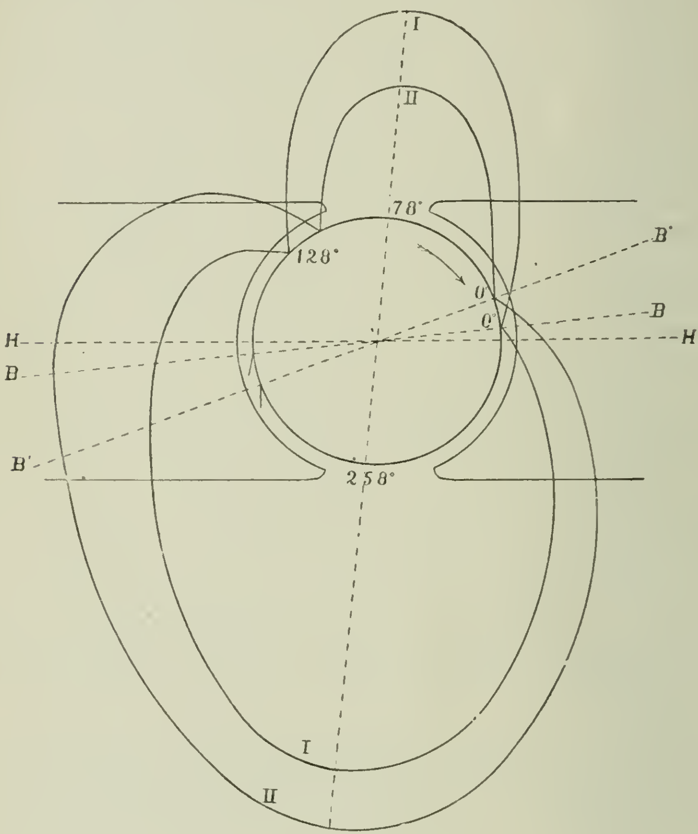


FIG. 1.

tive values are set off outside in the lower section of the diagram. The direction of rotation is clockwise. With no load the highest positive potential was about 78° behind the positive brush. From this point it fell again, and at 128° it was the same as that of the positive brush. For all the coils between 0° and 128° the integrated positive and

negative electro-motive forces exactly equal each other. The neutral plane falls evidently 78° behind the brush, or the brushes may be said to have a lead of 78°, with no increase in sparking. A negative maximum occurred at about 260°, and the potential difference between the positive and negative maxima was 644 volts. The same potential difference was found by direct measurement when two extra brushes were set at these points.

With a load equivalent to three lamps the brushes were rocked back 15° to bring the current to ten ampères. Hence, the zero of this curve begins 15° back from the zero of the first curve. Again, the observations are plotted and the positive maximum falls at the same place on the circle, and, therefore, at the same place on the commutator. The two maximum points are at about 65° and 245° from the positive brush and the two potential differences are 168 and 456 volts. Their sum this time is 624 volts, a little less than with no load. With the highest load carried the brushes were rocked backward about 50° further and the lead was then about 15°. The extreme potential difference obtainable this time did not exceed 600 volts. So far as can be discovered from these curves the neutral plane remains fixed, while the brushes move round the commutator to adjust to a constant current. I find no evidence in them that the forward movement of the brushes to control the current causes the neutral plane to move with them. As the brushes advance with a diminishing external load they put between them and the neutral plane an increasing number of armature-turns, generating counter electromotive force; and it is a striking fact that, when the field coils are not cut out, the back-turns on the armature cut down the potential difference between the brushes, not by a counter magneto-motive force apparently, but by counter electro-motive force; for the maximum potential difference to be found on the commutator is no less on no load than on full load, showing that at least as many lines of force traverse the armature core with the brushes far forward and with many back armature-turns as with the brushes in

the position for maximum load and with the back-turns reduced to a minimum.

THREE METHODS OF GOVERNING.

Assuming still practically constant speed, we next inquire into the methods employed to maintain a constant current without appreciable sparking by rocking the brushes round the commutator cylinder.

In one machine the brushes are moved automatically by means of a small electric motor and at the same time field coils are successively cut out as the brushes rock forward with a light load. A pair of brushes is used on each side and they are kept at a fixed distance apart. By these combined means the machine can be run on short-circuit with the normal current and without sparking.

Another system leaves the field coils constantly in circuit, but employs two pairs of brushes and varies the angular distance between the members of each pair when the brushes are moved. The movement of the brushes is effected mechanically in response to any change in the main current till the current is brought back to the normal value. In these machines the spread of each pair of brushes, or what is sometimes called the overlap of the brushes, is lessened as they rock forward toward the polar centres. Very satisfactory results are secured in this way.

In the third class of machines only one pair of brushes is used, which lap over about two or three commutator sections, and the regulation of the current is effected solely by the movement of this one pair without change of overlap and without disturbance of the ampère-turns on the field. The brushes are moved mechanically by means of an automatic regulating device. No less satisfactory results appear to be secured by this method than by the others, while the mechanism as a whole is somewhat simpler.

I have described these three methods for the purpose of pointing out their bearing on the theory and design of closed-coil Gramme rings for constant currents. The important question is not how to get the necessary electro-motive force with such a dynamo, but how to vary that electro-

motive force in response to the varying demands of the external circuit, without injurious sparking at the brushes.

The electro-motive force is controlled in all three of these methods by rocking the brushes, the other differences in the devices are made necessary for the suppression of the sparking. This brings us to a consideration of the most intrinsically interesting topic of the paper, viz: the conditions necessary to suppress sparking and the features of design required to furnish them.

SUPPRESSION OF SPARKING.

If we assume that the armature is well balanced electrically and magnetically, and that the brushes have a proper bearing in contact with a smooth commutator, the conditions required to commute the current without sparking are known to be as follows: With a two-pole dynamo, the current is divided through the armature, one-half going from brush to brush through one side, and the other half through the other. Hence, when an armature coil is carried past the brush it is transferred from the one circuit through the armature to the other, and at the same time the current through it reverses its direction. This constitutes the act of commutation. But the sudden decay of a current through a coil in one direction and its growth to an equal value in the other gives rise to an electro-motive force of self-induction opposing the change. This electro-motive force will prolong the flow of the current on one side of the brush and will oppose its rise on the other side. Hence, if the coil is short-circuited by the brush lapping over the two consecutive commutator segments to which its ends are connected, even when the coil passes the neutral plane of the dynamo, the electro-motive force of self-induction produces a local current through this coil; and when the one end of the coil slips past the brush and becomes a part of the other half of the divided circuit the current which should reverse through it meets the opposing current and breaks over the gap to the brush with a spark. Hence, the commutation must not take place at the neutral plane but in advance of it, and in a field where the induced electro-motive force in

the coil shall be just sufficient to offset the self-induction and in addition shall reverse the current in the coil while it is passing the brush or pair of brushes, and cause it to grow to the normal value at the instant when one end of it passes out from under the brush. The induction from the field must be sufficient to bring the one current to zero and to set an opposite one of equal value flowing in the coil, during the time it is under the brush. Then the commutation will be sparkless.

Now, if the current is kept constant in strength the field induction required to accomplish the results described is approximately the same whether the coil is short-circuited at one angle or another in advance of the neutral plane. It would appear at first thought that, unless the induction in every part of the field from the neutral plane to a point nearly 90° in advance of it is substantially uniform terrific sparking must result when the brushes are shifted far forward to vary the electric pressure to suit the requirements of the circuit; for if the induction is in excess of the requirements to accomplish the result described in the commuted coil then a current will circulate through it during the short-circuit, and the rupture of this on leaving the brush will cause sparking. I have illustrated this action in the following manner: Separately excite the field magnets of a machine, which can run on short-circuit even with a forward displacement of the brushes without sparking. Then leaving the armature on open circuit, rock the brushes forward: the sparking will increase with each advance till it becomes terrific and endangers the machine. The induction to which each coil is subjected in an excited field produces a large current in it while it is under the brush, since there is less self-induction in the coil to offset the induction from the field than there is when the machine is self-excited and working in the normal way. There is another reason to be described later.

Considerations of this kind have led some writers to say that sparkless commutation for any position of the brushes can be accomplished only when the induction in the field is made uniform. The Statter constant current machine in Eng-

land is made on this principle. Portions of the pole pieces are laboriously cut away at such points as to make the density of the lines of force entering the armature over a given angle equal. Of course, a machine built in this way will permit of shifting the brushes through a considerable angle in order to vary the potential difference without introducing sparking.

But while a uniform field accomplishes the result, no such uniformity is required; the same result may be secured in other ways. The first method already described weakens the field when the brushes move forward by cutting out ampère-turns in the field magnets. This reduces the induction to the proper amount at each point without changing the overlap of the brushes. It is made necessary by the very high saturation of the armature core in this machine. It has the advantage of greater economy with small loads because field resistance is cut out, but it requires a more complex arrangement of parts on the machine than suffices for the mere movement of the brushes.

[*To be concluded.*]

SUBDIVISION OF STEAMSHIPS AND SAFETY IN CASE OF INJURY.

By Andrew Ham.

[*Read at the meeting of the Section of Engineers and Naval Architects, November 23, 1893.*]

[*Concluded from p. 77.*]

The position *W L* (see *Fig. 3*) I suppose to be found in the usual way and start from this imaginary position.

Now, we may suppose the water contained in the ship up to *W L* to be solid, and to form part of the ship (say); it freezes without altering its density, provided that in the way of the compartments the sea has free access to the parts above *W L*—which we may express by saying that the part *n p q s t r u v n* of the load water plane is ineffective for giving stability.

This part we call the lost area of load water plane: that

part of the water plane which is left we call the effective water plane.

We readily see that:

(1) The ship begins to turn around an axis $A_1 A A_2$.

(2) This axis passes through the centre of area A of the effective water plane and makes a small angle with the longitudinal axis of the ship. (See Appendix.)

For practical purposes this axis may be supposed to coincide with the fore and aft line through A.

(3) The ship will heel over till the centre of gravity, for

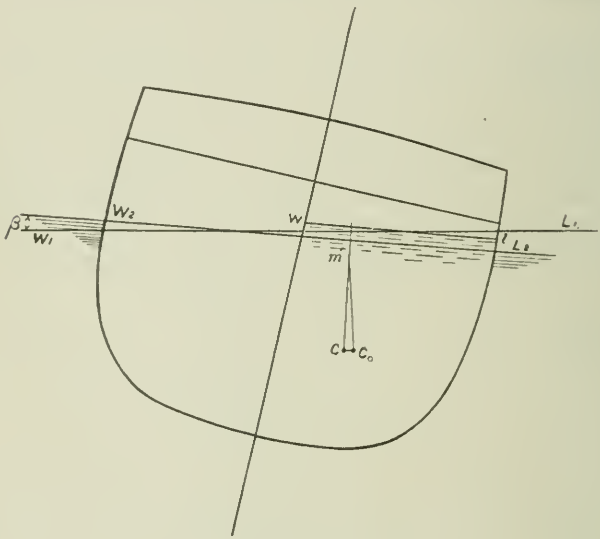


FIG. 2.

the imaginary case (*i. e.*, ship and frozen water in compartments combined) lies in the vertical line passing through the centre of buoyancy of the total displacement minus the wedges above the lost area of water plane.

(4) It follows that volume wedge $W A W_1$ = volume effective wedge $L A L_1$ and the couple which these wedges give:

$$M = J.\ \delta.\ sin\ \theta, \text{ approximately.}$$

J being the moment of inertia of the effective water plane about $A_1 A_2$.

δ the weight of a cubic unit (of length) of water.

θ the angle of heel.

(5) The ship will behave in exactly the same way as the uninjured ship would behave, only the metacentric height is

$$M\,C_0 = \frac{J}{V + \Delta V}$$

V being the volume of displacement of the uninjured ship.

ΔV being the volume of the water in the compartment up to $W\,L$, which we suppose to be solid.

If G_0 be the centre of gravity for the uninjured ship, g_0 the centre of gravity of the solid water, then we find the centre of gravity for the two combined in G.

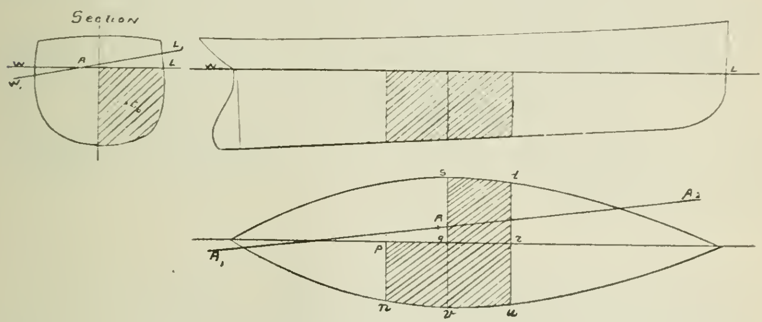


FIG. 3.

Let C_0 be the centre of buoyancy for the imaginary case, *i. e.*, the centre of volume of the hull below $W\,L$.

To find the position of equilibrium, set off

$$C_0\,M = \frac{J}{V + \Delta V}$$

draw $M\,G$ and find θ by measuring.

[NOTE.—In general, the lost part of the water plane is not totally ineffective, and we have to deduct only a certain percentage of its area, moment and moment of inertia, percentage which is the same as that of the compartments below.]

We have found the position of statical equilibrium of the injured ship. This is the position around which the ship oscillates when rolling in still water or on the waves.

A problem, distinctly different from the one solved, is: What will be the stability of the ship now? and I will proceed to settle the remaining point.

I start with another supposition, viz: that the ship be flooded up to $W_1 L_1$ (*Fig. 1*), but uninjured, for instance, that we fill the compartment by pumping water in it up to $W_1 L_1$. Next, we incline the ship through a small angle β; then the section of the surface of the water in the compartment will be $w\,l$. In this inclined position the centre of volume of the flooding water will have moved from C_0, its position for the position of equilibrium, to c. Calling ΔD the weight of the water in the compartment, we might suppose ΔD concentrated in C.

But this centre moves away with every inclination the ship takes, and its position is a function of that inclination, and the form of the boundaries of the compartments.

If we draw a line through c_1 square to $w\,l$, it intersects a vertical line through C_0 in a point m. This point will be nearly constant for all inclinations: it is, in fact, nothing but the metacentre of the body of water in the compartment. The locus of c is a circle, with a radius $c_0\,m$ and its centre in m and

$$m\,c_0 = \frac{i}{\Delta v}$$

i being the moment of inertia of the surface $w\,l$ in regard to a longitudinal axis passing through its centre.

Δv being the volume, corresponding to ΔD.

So that the water will act in the same manner as a weight ΔD, fixed in m, would act.

Now, when the injured ship is rolling, there will be no time for the sea to fill the space between $W_2 L_2$ and $w\,l$; or, as in *Fig. 2*, for the water between these planes, to flow out. Consequently our supposition is practically realized.

To calculate the stability of the ship, therefore, we must suppose the water plane to be effective over its whole area, provided that we take the centre of gravity of the ship to be that of the uninjured ship and, ΔD supposed fixed in m, combined.

This calculation, however, would be of little use. For nobody knows what the water will do. It may have a natural period of oscillation, non-isochronous with the period of rolling of the ship and then its effect may be most dangerous.

And again, its period may be such as to counteract the rolling of the ship, in which case it will act as a water chamber.

This natural period of oscillation cannot be calculated, but might be found by tank experiments in a way similar to Froude's experiments, and based on the universal law of mechanical similarity. It will mostly depend on the height of water above the upmost immersed deck or flat. For the water below such a deck takes no part in the oscillating motion; it is bodily elevated or lowered.

That the effect of free water inside a ship is tremendous is proved by experience with water chambers. To reduce the rolling by fifty per cent., a properly constructed water chamber, containing one-two-hundredths of the displacement, was found sufficient; that is to say, for the *Lucania* about eighty tons would have this effect.

November 13, 1893.

APPENDIX.

Position of axis $A\ A'$.

Let us assume a system of coördinate axes, the origin being in A, $A\ Y$ situated in the water plane $W\ L$ and parallel to the plane of symmetry of the ship, $A\ X$ being perpendicular to that plane. The boundary of the water plane is the water line; its equation be

$$x_0 = f(y) \tag{1}$$

Let α be the angle which $A_1\ A_2$ makes with $A\ Y$ (*Fig. 4.*)

M the magnitude of that couple.

$d\,F = dx\ dy$ an element of the water plane.

μ its percentage, $\mu = 1$ for effective area.

δ the weight of a cubic unit of water.

p the distance of $d\,F$ from $A_1\ A_2$.

θ the angle of inclination.

β the angle which the axis of the couple, tending to heel the ship, makes with $A\ Y$.

Then M may be resolved in

$$M_x = M \sin \beta$$

$$M_y = M \cos \beta$$

The weight of an elementary perpendicular cylinder of the wedge, the base of which is $d\,F$ is

$$\mu \,.\, \delta \,.\, p \tan \theta \; d\,F = d\,P$$

giving p its proper sign.

The conditions of equilibrium are expressed by the following equations:

$$-M \sin \beta = \int y\, d\,P = \delta \,.\, \tan \theta \,.\, \int y \,.\, p \,.\, \mu \,.\, d\,F \qquad (2)$$

$$-M \cos \beta = \int x\, d\,P = \delta \,.\, \tan \theta \,.\, \int x \,.\, p \,.\, \mu \,.\, d\,F \qquad (3)$$

$$o = \int d\,P = \delta \,.\, \tan \theta \int \mu\, p\, d\,F \qquad (4)$$

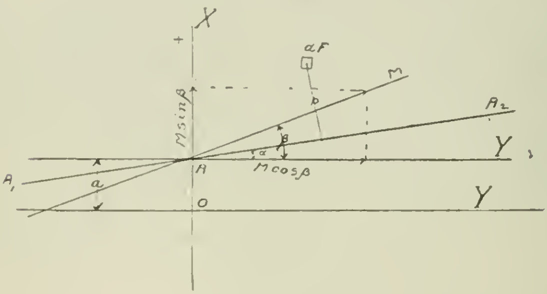


FIG. 4.

The limits of these integrals being determined by (1)

$$x_0 = f(y)$$

(4) shows that $A_1\, A_2'$ must pass through the centre of the water plane.

(2) and (3) give M in function of β, x_0, y and p.

But

$$p = x \cos \alpha - y \sin \alpha \qquad (5)$$

consequently

$$-M \sin \beta = \delta \,.\, t\,g\, \theta \int (x\, y \cos \alpha - y^2 \sin \alpha)\, \mu\, d\,F \qquad (6)$$

$$-M \cos \beta = \delta\; t\,g\, \theta \int (x^2 \cos \alpha - x\, y \sin \alpha)\, \mu\, d\,F \qquad (7)$$

or

$$-\frac{M}{\delta\; t\,g\, \theta} \sin \beta = \cos \alpha \int x\, y\, \mu\, d\,F - \sin \alpha \int y^2\, \mu\, d\,F \qquad (8)$$

$$-\frac{M}{\delta\; t\,g\, \theta} \cos \beta = \cos \alpha \int x^2\, \mu\, d\,F - \sin \alpha \int x\, y\, \mu\, d\,F \qquad (9)$$

$\int x\, y\, \mu\, d\,F$ is called the product of inertia.

$\int y^2\, \mu\, d\,F$ is the longitudinal moment of inertia of the water plane.

$\int x^2 \mu \, d F$ is the transverse moment of inertia of the water plane.

$\int x \, y \, \mu \, d F$ is a quantity which becomes $= o$ when $O X$ and $O Y$ are principal axes of inertia of the injured water plane.

In the case which we consider

$$\beta = o \therefore \sin \beta = o$$

consequently, from (8)

$$\tan \alpha = \frac{\int x \, y \, \mu \, d F}{\int y^2 \, \mu \, d F} \tag{10}$$

which shows that α is the quotient of the product of inertia by the longitudinal moment of inertia.

Let F_0 be the total intact water plane, F_1, F_2, F_3, etc., the parts of the lost area, covering the respective compartments, ΔV_1, ΔV_2, ΔV_3, etc., μ_1, μ_2, μ_3, the corresponding percentages.

As μ_1, μ_2, μ_3, etc., are uniform over the respective areas, F_1, F_2, F_3, we may write:

$$\int_o^F \mu \, x^2 \, d F = \int_o^{F_0} x^2 \, d F_0 - (1 - \mu_1) \int_o^{F_1} x^2 \, d F_1 -$$

$$- (1 - \mu_2) \int_o^{F_2} x^2 \, d F_2 \tag{11}$$

$$\int_o^T \mu \, y^2 \, d F = \int_o^{T_1} y^2 \, d F_0 - (1 - \mu_1) \int_o^{F_1} y^2 \, d F_1 -$$

$$- (1 - \mu_2) \int_o^{F_2} x^2 \, d F_2 \tag{12}$$

$$\int_o^F \mu \, x \, y \, d F = \int_o^{F_0} x \, y \, d F_0 - (1 - \mu_1) \int_o^{F_1} x \, y \, d F_1 -$$

$$- (1 - \mu_2) \int_o^{F_2} x \, y \, d F_2 \tag{13}$$

where the limits of the integrals are determined by the boundaries of the respective areas.

To determine the value of the product of inertia of an area, we write:

$$\int x\, y\, d\, F = \int \int x\, y\, dy\, dx \tag{14}$$

As to the limits of the double integral, I remark that eq. (1)

$$x_0 = f\,(y)$$

admits two values of x for every value of y. One of these, x_0' is negative, the other: x_0'' may be positive or negative, but always $x_0' < x_0''$, except at the ends: ($y = -l_1$ and $y = +l_2$) where $x_0' = x_0 = -a$ when a is the distance of A from $O\,Y$, the centre line of the intact water plane.

Consequently,

$$\int_0^F x_0\, y\, d\, F = \int_{-y_0}^{+y_1} \int_{x_0'}^{x_0''} x_0\, y\, dy\, dx_0 \tag{15}$$

Now we have, for both positive and negative values of x'',

$$\int_{x_0'}^{x_0''} x\, y\, dx = \int_{n'}^{0} x\, y\, dx + \int_0^{x_0''} x\, y\, d\, x = -\frac{x_0'^2}{2} y + \frac{x_0''^2}{2} y \tag{16}$$

Consequently (15) becomes

$$\int_0^F x_0\, y\, d\, F = ½ \int_{-y_0}^{y_1} (x_0''^2 - x_0'^2)\, y\, dy \tag{17}$$

which permits us to find the value of the product of inertia of any figure by Simpson's or any other approximating rule.

We will, however, try to simplify (13).

Let us write the equation of the water-line, taking $O\,Y$ and $O\,X$ as axes

$$x = \varphi\,(y) \tag{18}$$

then, this equation admits two values, x' and x'', the latter being positive, while

$$-x' = +x'' = x$$

(18) is obtained by changing x_0 in (1) in $x - a$, and

$$\left.\begin{aligned} x_0' &= x' - a = -x - a \\ x_0'' &= x'' - a = x - a \end{aligned}\right\} \tag{19}$$

consequently, by (17) and (19)

$$\int_{o}^{F_0} x_0\, y\, d\, F_0 = -\, 2\, a \int_{y_0}^{y_1} x\, y\, dy \qquad (20)$$

but in (20)

$$\int_{y_0}^{y_1} x\, y\, dy$$

is the moment of the figure about $o\,x$, so that (20), translated, says:

The product of inertia of a symmetrical figure about axes $A x$, $A\,Y$, $A\,Y$ being parallel to the axis of symmetry of the figure at a distance a from that axis, $A\,X$ being square to $A\,Y$, equals the product obtained by multiplying the moment of the figure about $A x$ by $-\,2\,a$.

This, consequently, is not only true for F_0, but also holds good for those areas F_n which are situated in compartments without a longitudinal bulkhead.

For compartments with a longitudinal bulkhead $b\,b$, we have

$$\left.\begin{aligned} x_0' &= -\,x - a \\ x_0'' &= c - a \end{aligned}\right\} \qquad (21)$$

c being the distance of the bulkhead from the centre line $O\,Y$, positive or negative.

Consequently, by (17) and (21)

$$\int_{o}^{F_n} x_0\, y\, d\, F_n = \tfrac{1}{2} \int_{l_{n-1}}^{l_n} \left\{ c\,(c - 2\,a) - x\,(x + 2\,a) \right\} y\, dy \qquad (22)$$

l_{n-1} and l_n being the values of y for the bounding transverse bulkheads b_{n-1} and b_n.

To simplify, we suppose $c = o$ as is generally the case in practice, making

$$\int_{o}^{F_n} x_0\, y\, d\, F_n = -\,\tfrac{1}{2} \int_{l_{n-1}}^{l_n} x^2\, y\, dy - a \int_{l_{n-1}}^{l_n} x\, y\, dy \qquad (23)$$

Now, according to (17)

$$- \tfrac{1}{2} \int_{l_{n-1}}^{l_n} x^2\, y\, dy$$

is the product of inertia of F_n about $O\,Y$, $O\,X$.

And

$$\int_{l_{n-1}}^{l_n} x\, y\, dy$$

is the moment of F_n about $O\,X$.

Let us denote by F_n in general those areas which are symmetrical about $O\,Y$, M_n their moments about $O\,X$.

F_m those areas which are on one side of $O\,Y$, M_m their moments about $O\,X$, L_m their products of inertia about $O\,X$, $O\,Y$.

Then, by virtue of eq. (20) and (23), eq. (13) becomes

$$\int_o^F x\, y\, \mu\, d\, F = - 2\, a\, M_o + 2\, a\, \Sigma\, (1 - \mu_n)\, M_n +$$
$$+ a\, \Sigma\, (1 - \mu_m)\, M_m - \Sigma\, (1 - \mu_m)\, L_m \qquad (24)$$

But, as A is the centre of area of F

$$o = M_o - \Sigma\, (1 - \mu_n)\, M_n - \Sigma\, (1 - \mu_m)\, M_m \qquad (25)$$

eq. (24) becomes

$$\int_o^F x_o\, y\, d\, F = - a\, \Sigma\, (1 - \mu_m)\, M_m - \Sigma\, (1 - \mu_m)\, L_m \quad (26)$$

where

$$L_m = - \tfrac{1}{2} \int_{l_{m-1}}^{l_m} u^2\, y\, dy$$

Or:

The product of inertia of the effective water plane is equal to the sum of certain functions of the lost areas F_n on one side.

This function for such an area F_n is the sum of two quantities. The first is its moment about $O\,X$, multiplied by $- a\, (1 - \mu_n)$. The second is the product of inertia of that area about $O\,X$, $O\,Y$, multiplied by $-(1 - \mu_n)$.

Franklin Institute

[*Proceedings of the annual meeting, held Wednesday, January 17, 1894.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 17, 1894.

Mr. SAMUEL SARTAIN in the chair.

Present, 228 members and thirty-six visitors.

The annual election resulted in the choice of the following candidates, viz:

For *President*	(to serve one year), . . .	JOSEPH M. WILSON.
" *Vice-President*	(" three years), . . .	W. P. TATHAM.
" *Secretary*	(" one year), . . .	WM. H. WAHL.
" *Treasurer*	(" " "), . . .	SAMUEL SARTAIN.
" *Auditor*	(" three years), . . .	W. O. GRIGGS.

For the *Board of Managers* (to serve three years).

ARTHUR BEARDSLEY,	CHAS. G. DARRACH,	M. R. MUCKLE, JR.,
HENRY BOWER,	HENRY R. HEYL,	HENRY PEMBERTON, JR.,
CHAS. A. BRINLEY,	H. W. JAYNE,	HORACE PETIT,

For the *Committee on Science and the Arts* (to serve three years).

H. BRINTON,	SPENCER FULLERTON,	S. P. SADTLER,
JOHN E. CODMAN,	W. C. HEAD,	CLARENCE B. SCHULTZ,
H. F. COLVIN,	HENRY R. HEYL,	THOS. SHAW,
THOS. P. CONARD,	FRED. E. IVES,	E. G. WILLYOUNG,
CHAS. B. DUDLEY,	C. L. PRINCE,	PAUL A. WINAND.

The annual reports of the Board of Managers, of the several Standing Committees and Sections of the Institute, and of the Trustees of the Elliott Cresson Fund, were presented and accepted.

Mr. George D. Burton, of Boston, who was present by special invitation, read a paper descriptive of his method of heating metals by the employment of a saline electrolytic bath as a resistance. He proceeded to give an extremely interesting practical demonstration of the method, with an apparatus consisting of an ordinary wooden bucket containing a saturated aqueous solution of a mixture of sal soda and borax, a lead plate connecting with the positive terminal of a direct current serving as the positive electrode (or anode), and the metallic object to be treated connected with the negative terminal of the circuit serving as the negative electrode (or cathode), the circuit being completed through the salt solution, where the metallic article forming the cathode is brought in contact with, or immersed beneath the sur-

face of the bath. This disposition of apparatus is the invention of Mr. Burton, and has been appropriately named the "water-pail forge." The circuit employed by Mr. Burton in his experiments was the 220-volt Edison incandescent service. With the apparatus installed in the manner described above, Mr. Burton successfully exhibited the efficiency by heating to bright incandescence, and even to fusion, in from ten to thirty seconds, rods and bars of iron, steel, copper and carbon. The metal objects were then forged, welded, etc., in the anvil.

The demonstration excited fresh interest and considerable discussion followed, at the close of which the thanks of the meeting were voted to Mr. Burton for his extremely interesting demonstration, and the subject was directed to be referred to the Committee on Science and the Arts for investigation and report.

Prof. Joseph W. Richards gave some account of the methods that had heretofore been described and used for soldering aluminum, and referred to the very serious difficulties which inventors had met in their efforts to find a practical method. He then proceeded to describe the plan devised by his father, Mr. Joseph Richards, which involves the use of phosphorized alloys for the purpose, the function of the phosphorus being to remove the thin film of oxide always present on the surface of aluminum, and which renders soldering so very difficult. At the close of the remarks the application of the method was shown practically, in a very satisfactory way.

The meeting passed a vote of thanks to Mr. Richards for his interesting demonstration and the subject of the invention was referred to the Committee on Science and the Arts.

The Secretary read a brief description of an improved system of electric railway conduit, devised by Mr. Wm. R DeVoe, of Shreveport, La., and illustrated the subject by the exhibition of a model. The Secretary also referred to a method of depositing metallic chromium electrolytically, devised by M. Placet, a French electrician, and exhibited specimens of the metal and of a number of articles of copper that were electroplated with chromium. These specimens were sent for exhibition by Mr. Anthony Pollok, of Washington, D. C.

A letter was read from Mr. Wm. Sellers declining a renomination to membership on the Board of Managers. Whereupon, on motion of Mr. John H. Cooper, duly seconded, the following resolution was unanimously adopted, viz:

Resolved, That the Institute accepts the resignation of Mr. Wm. Sellers with regret, and directs that record be made in its proceedings of its high appreciation of his long and useful services as a member of its Board of Managers and its President.

Adjourned. WM. H. WAHL, *Secretary*.

PLATE 3.—Taking the ladle of glass from the furnace. (American Wire Glass Manufacturing Company, Tacony, Philadelphia.)

PLATE 2.—Glass rolling tables; glass melting furnaces; annealing ovens in foreground. (American Wire Glass Manufacturing Company, Tacony, Philadelphia.)

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SHUMAN'S PROCESS AND APPARATUS FOR EMBEDDING WIRE NETTING IN GLASS.

[*Being the report of the Institute by its Committee on Science and the Arts, adopted November 1, 1893*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 1, 1893.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, by its Committee on Science and the Arts, investigating Shuman's process and apparatus for embedding wire netting in glass, finds as follows:

The object of this invention is to strengthen, or reinforce, sheets of glass of various dimensions intended to be used for roof lights, partitions, vault and pavement lights, port and deck lights, etc., by inserting a metallic netting into the body of the glass sheets at the time they are rolled

with the view of protecting the glass against fracture and of preventing fragments of fractured sheets from detaching themselves in case of accident.

The present mode of protecting glass skylights is to suspend copper wire netting immediately beneath the glass, the wire being fastened to a framework holding the glass. In situations exposed to smoke, corroding gases and other destructive influences, as in railway stations, chemical works, etc., this practice is attended with serious objections, for the reason that, in such situations, even copper and brass wire will become corroded and will then be worthless as a protection against the fall of large fragments of glass, should the skylights become broken.

The enormous extent to which wire netting is used thus to protect skylights was strikingly illustrated at the late World's Columbian Exhibition in Chicago, where 1,045,000 square feet of wire netting was placed under the glass roofs of four of the main exhibition buildings.

The use of wire netting in such a manner that it cannot be corroded and, at the same time, will reinforce and strengthen the glass (which, in the old practice, the netting does not do), would obviously be a great step in advance and one which should commend itself to architects and engineers, and the advantages of embedding the wire in the glass itself to accomplish these objects are so manifest that further comment would seem unnecessary.

In examining the prior state of the art of producing sheets of glass with metallic enclosures for the purpose of strengthening and guarding the same, the following references, bearing more or less directly on the subject, have been found and consulted.

The first invention, showing wire netting embedded in glass, is the British patent, No. 1,528, of 1855, granted to Newton for fire- and burglar-proof glass. This patent describes the depositing of a quantity of molten glass into a mould, then placing on the glass a sheet of wire gauze, then placing upon the wire another quantity of molten glass, and finally pressing the mass into a sheet. The wire is prevented from projecting beyond the glass by constructing the mould in

two parts and mounting the wire between the parts; it is claimed that several sheets of wire cloth can be thus intro duced into the glass.

The British patent of Hyatt, No. 1,482, of 1871, describes a method of making glass with wire embedded in it, by casting the glass on both sides of the wire work. Hyatt proposes to bend or undulate the wire by coiling it in the form of a helix, so as to allow for expansion and contraction to avoid fracture.

The British patent granted to Lake as a communication from Becoulet and Bellet, of Paris, France, No. 9,226, of 1876, describes the following method:

"A layer of fused glass of one-half the thickness required is spread upon a table, a net work of iron wire, previously polished, is placed upon the glass, another layer of glass is placed on the wire, over which a roll is passed."

The British patent granted to John Armstrong, No. 5,701, of 1887, describes a machine for embedding wire in glass. "The ordinary table and roll is used, and in front of the roll is a guide roller, under which the wire is passed from a reel. The wire is fixed at one end of the table and brought under both rolls; the wire is pressed against the incandescent glass and partly enters it, the hot glass coming through the meshes to the upper side. The roll passes over the glass and wire, squeezing the glass out to the required thickness.

The following United States patents, Nos. 229,907, 229,-928 and 222,768, of 1879, granted to Arbogast, for glass insulated electric conductors and methods of making the same, and No. 355,486, of 1887, to Thompson, for wire-embedded enamelled ware, need no special mention.

German patent No. 46,287, of 1888, to Armin Tenner, and published March 18, 1889, is next in order. This patent discloses a process similar in many respects to the early British patent of 1855.

The process is as follows: "A mass of molten glass sufficient for making one-half the thickness of the plate desired is poured into a suitable mould and then rolled or pressed; then the metal inlay is introduced, consisting preferably of wire gauze; then sufficient glass is poured on to make the

desired thickness and the whole rolled or pressed and finally tempered."

The German patent of Sievert, No. 60,560, of 1891 (published February 5, 1892), follows Tenner, but describes a different method, to wit:

"A platen is used of the shape corresponding to the size of the sheet to be made. The bottom of this platen is provided with a pattern. A pattern can be formed in strips, corrugations, facets and eyes of all kinds, so that the upper edge of this pattern forms the bed for the metal inlay to be enclosed in the glass. The metal inlay is distributed on the upper edge of the pattern, and then by pouring in the liquid glass, and, if necessary, afterwards rolling, pressing and cooling off, the glass plate is produced; then on the pouring in and penetrating of the liquid glass into the depressed pattern of the mould the metal inlay will be raised, as experiments have shown, so as to be within the mass of glass."

British patent, No. 11,039, was granted to Sievert in 1891 (published April 30, 1892), for the same process described in the German patent of 1891, with additional matter, as follows, as a modification, viz:

"A mould with a smooth bottom may be employed and the design or pattern may be formed on the lower surface of the presser or plunger which is adapted to enter the mould and press down the molten glass. In this case the wire gauze is fixed by means of pieces of string or other suitable material underneath the lower surface of the plunger, so that the gauze rests against the edges of the design and is pressed into the mould, the pieces of string immediately breaking or being burnt by the heat of the molten glass. The glass enters into the cavities of the design or pattern and acts to press the metal inclosure so far down that the latter is actually inclosed in or surrounded by the glass."

It is also stated in the specification that the glass may be pressed down by pressure or rolling so as to receive an even surface.

The Shuman patents, Nos. 483,020 and 483,021, of Sep-

PLATE 4.—Rolling the sheet; pouring the ladle of glass on table. (American Wire Glass Manufacturing Company, Tacony, Phila.)

PLATE 5.—Carrying off the rolled sheet from the table. (American Wire Glass Manufacturing Company, Tacony, Philadelphia.)

tember 20, 1892, are next in order, and, as far as can be found, are the only patents granted in the United States for embedding wire netting in glass.

From the preceding sketch, it is made evident, that the idea of inserting a wire netting into sheets of glass while the glass is in a plastic condition, is by no means a new one, although its development on the commercial scale, until very recently, has not been successful.

The first attempts to put the idea into practice appear to have been made in England, some twenty years ago, by Thaddeus Hyatt, whose British patent, No. 1,482, of 1871, is referred to above, and concerning which we give the following additional details:

A section of wire netting is securely clamped in a frame of cast iron of a thickness equal to that of the glass sheet to be made. This frame is then laid upon a flat table, and sufficient glass to form a sheet poured into it. By means of a hydraulic press, part of the glass is forced through the meshes with the view of getting the glass on both sides of the netting; or, in other words, placing the netting as near as possible in the centre of the glass sheet. While this seems very simple in theory, Hyatt appears to have encountered great difficulty in forcing the glass through the meshes when a fine netting was used. To obviate this difficulty, a square or round hole was made in the centre of the section of wire netting in order to facilitate the flow of glass underneath.

The netting was thus necessarily subjected to a severe strain in forcing the glass through the meshes, and, since the metal becomes red hot by its contact with the molten glass, it will evidently stretch and sag when pressure is applied to it, thus making it impossible to keep the netting even approximately in the centre of the glass sheet. Another objection to this method is that the dimensions of the glass sheet are limited to the size of the face of the plunger of the hydraulic press. Hyatt's process was apparently found to be impracticable, and, so far as can be determined, his product never became a commercial commodity.

The patent of Armstrong (British patent, No. 5,701, of 1887) appears to come nearer to the practical solution of the problem than any which preceded those of Shuman.

In Armstrong's case a clever attempt is made to realize practically the plan of pressing a wire netting, by means of a heavy roller, into the body of a sheet of glass, and then covering the wire up in the glass by the pressure of a second roller following the first one. The mechanism by which it was attempted to carry out this idea, though embodying the elements of a useful invention, was seriously defective, and the inventor does not appear to have made any effort to improve it.

Concerning the subsequent inventions of Tenner and Sievert, it may best serve the purpose of setting forth the marked differences between them and the Shuman process, to give, in as much detail as possible, an account of the methods of procedure described therein.

In Tenner's German patent (No. 46,287, of 1888), a sheet of glass, one-half the thickness of the sheet desired, is first rolled out with a smooth roll on a flat table, in the ordinary way; then a sheet of wire netting, which has previously been made red hot, is laid upon it; another sheet of glass, one-half the thickness of the plate desired, is then rolled or pressed over the wire netting, and the whole is then subjected to hydraulic pressure, and finally annealed in the usual manner.

With this method, it is said, great difficulty has been experienced in making sheets of any considerable size; that is, of more than two feet square. It is also stated to be expensive to operate.

In Sievert's German patent (No. 60,560, of 1892), the mould in which the glass sheet is to be cast is provided with corrugations, or ridges, the upper edges of which serve as points of support to metallic bodies to be enclosed. After placing the metallic objects in position the melted glass is poured into the mould, whereupon the entering glass lifts the metallic object sufficiently, so that after the sheet is finished the metallic body will be incorporated approximately in the body of the glass sheet. This method, there-

fore, is in some sense an improvement on the method of Tenner, since it is unnecessary to produce two layers of glass, and to unite the one with the other.

In Tenner's process, the manner of incorporating the metallic netting, etc., by laying the metal upon one sheet of glass, then rolling or pressing a second sheet upon it, is liable to cause severe strains in the finished glass, and for this reason the statement that the plan is limited to the production of sheets of small size, would appear to be well founded.

Hyatt and Sievert, it will be recalled, cast the glass in a mould and incorporated the metal with the glass in one operation, and, in this respect, they represent an improvement on the process of Tenner. It is apparent, nevertheless, that in all the processes antedating Shuman's, excepting that described by Armstrong, the size of sheets produced must be limited by the difficulty of making moulds of large size.

According to a publication which appeared in the Paris *Revue Industrielle* (April 8, 1893), under the title "Les Vitres Armées" (Guarded Glass), the idea of embodying a metallic trellis work (treillage métallique), or wire netting, with the glass, is of French origin. We quote as follows:

"An application for a patent was made ten years ago by a large mirror manufacturer in the Rue de Deux-Ecus in Paris, and experiments were successfully made in the glass works of Messrs. Appert Brothers, of Clinchy, and also in the foundries of Jeaumont. The results thus obtained proved that the idea, however simple and practical it might appear, was devoid of practical results; the metallic netting suddenly assuming such a high temperature bends and twists and is with great difficulty kept in the mass of glass."

The article alleges, further, that the amount of labor required to manufacture this glass renders it so very expensive that it cannot compete with the modern process of making ordinary roofing glass. Another objection alleged in the article, is that it is absolutely necessary to know beforehand the dimensions of the required sheets, for when once made it becomes almost impossible to cut them.

Neither the French patent above referred to, nor any other reference to it, could be found, and consequently no idea of the method employed can be formed. Numerous attempts have been made in this country to incorporate a wire netting in molten or plastic glass, but here also no record exists, or could be found, of any such attempts that had met with success prior to those of Shuman.

By the Shuman process the wire netting is inserted into the glass whilst a sheet is being rolled, the wire being heated, just before its incorporation, to a temperature near the melting point of glass. The wire netting thus incorporated with the glass forms part of the sheet itself and it cannot by any means short of violence be detached or removed therefrom. Of course, such a sheet may become cracked and portions detached from and expose the wire; but even in such case, there are so many points of attachment that it would hardly be probable that sufficient corrosion could take place to seriously weaken the wire and damage the sheet, no matter how many fine cracks it might contain through which the corrosive influences could work their way to attack the metal.

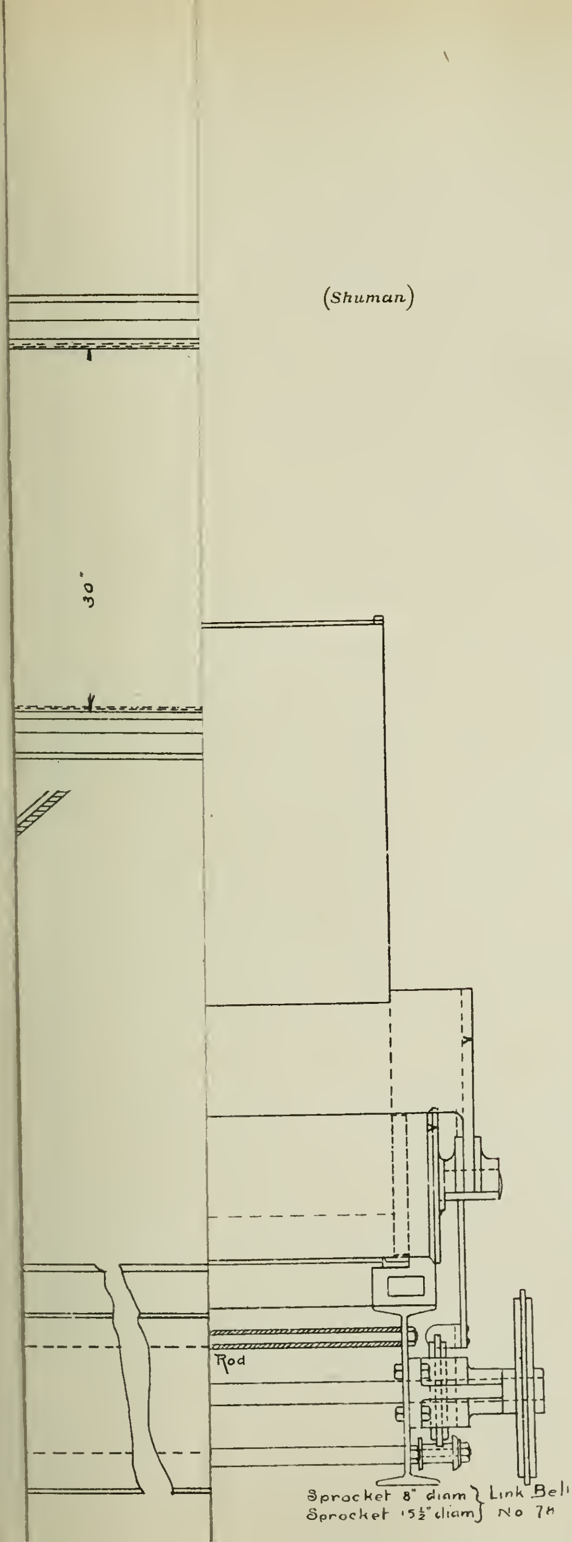
The inventions of Shuman form the subject of two letters-patent of the United States, herein referred to, one covering the details of the machine, and the other the features of the process. In the following description, reference will be made to both of these specifications without special distinction, as it will be convenient to regard them for the purpose of this investigation as a single invention.

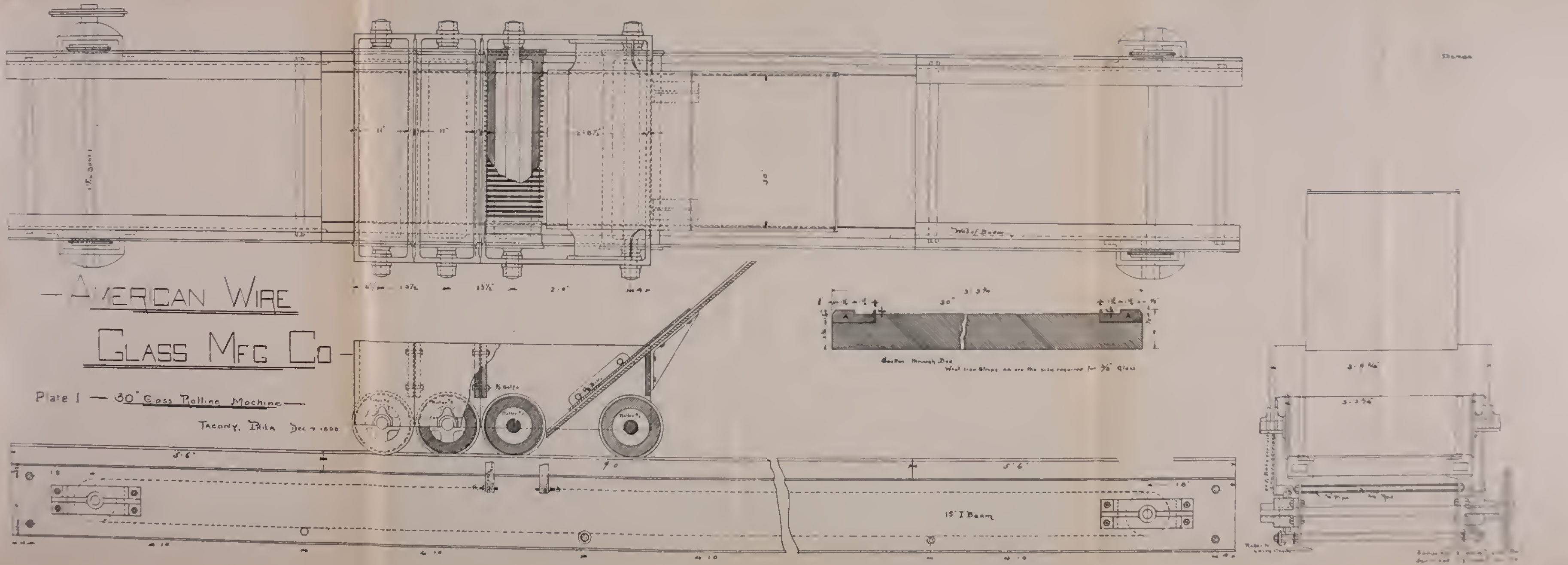
The following description of the method of manufacture, freely collated from the Shuman patents, will be understood by reference to the accompanying sheet of sectional views (*Plate 1*) of a thirty-inch glass-rolling machine, showing the same in plan, longitudinal and transverse sections, and by an inspection of the several reproductions made from photographs taken in the works of the American Wire Glass Manufacturing Company, at Tacony, Philadelphia. (See *Plates 2* to *9*.)

The sheet of drawings (*Plate 1*) represents the table upon which the glass is rolled, and which is arranged so

PLATE 6.—Pushing the rolled sheet from tray into the annealing oven. (American Wire Glass Manufacturing Company, Tacony, Philadelphia.)

PLATE 7.—View of interior of works, showing portions of annealing ovens, glass furnaces, rolling platforms, etc. (American Wire Glass Manufacturing Company, Tacony, Philadelphia.)


(Shuman)
30"
Rod
Sprocket 8" diam
Sprocket 15½" diam
Link Belt
No 78


AMERICAN WIRE
GLASS MFG CO
Plate I — 30" Glass Rolling Machine
TACONY, PHILA
Web of Beam
Section through Bed
15" I Beam
30"
5' 6"
9' 0"

that it may be heated from below by large gas jets, prior to beginning work. The table is made preferably of cast iron, and is provided on each side with ribs of sufficient height to allow for the rolling of the glass, and on the outer edges are rails upon which the rolls travel. On each side are rails, supporting the carriage before and after its travel. These rails are mounted in any suitable manner and are in line with the rails of the table.

The carriage is provided with four rolls, a front smoothing roll, a ribbed roll and two following smoothing rolls. It is moved across the table by power transmitted by means of a sprocket wheel and link belt. The front roll is intended to smooth out the molten glass after it is poured out upon the table and prepares it for the reception of the wire netting.

An inclined chute, for feeding the wire netting to the glass as this is spread by the front roll, is shown in connection with the carriage, arranged at the proper angle, and has a trigger, or other stop, at its lower end to detain the sheet of wire netting placed thereon until the proper time to discharge it upon the glass. The sheet of wire netting is preferably heated to the proper degree, so that it will not chill the glass when it is placed thereon. Directly back of the chute is a roll independently mounted in the carriage and having on its periphery a series of annular ribs (see plan) so arranged in reference to the table, as to press the wire netting into the molten glass. The ribs may be so arranged that although all the wire is incorporated in the molten glass some portions thereof will be pressed more deeply than others, thus corrugating the wire within the glass, if this be desired.

A smoothing roll directly behind the ribbed roll then passes over the glass and closes up the openings made by the ribbed roll and wire, completing the rolling of the glass. A second smoothing roll is preferably employed, as shown in the drawings, in order to correct the tendency of the rolled sheet, while still in the plastic state, to curl up over the first rear smoothing roll.

The finished glass is then removed and placed in an annealing furnace (see *Plates 5* and *6*). After the glass has

been annealed any glass or wire projecting over the edges of the sheet is cut off, after which the glass is ready for the market. The wire is preferably cut to the proper size prior to its application to the glass. The three smoothing rolls support the carriage, the ribbed roll being so mounted therein that it is free to rise or fall independently of the carriage. Thus, by raising this roll when the carriage is returning it will be clear of the glass. In order properly to handle the glass, the smoothing rolls are made hollow, and the heads are perforated to admit a gas pipe with jets for heating the rolls before beginning work. The rolls when thus brought to the proper temperature will not chill the glass during the process of rolling.

In operating the process a sufficient quantity of glass is poured upon the table at a point immediately in front of the first roll (*Plate 4*). As the carriage is moved forward, the roll smooths out the molten glass to the proper thickness, after which the wire netting is delivered upon the molten glass and pressed into it by the following ribbed roll. The next following smoothing roll closes the openings and corrugations made by the netting and ribbed roll. By this means a sheet of glass is produced with strips of wire, or a sheet of wire netting embedded therein. By having at certain distances, a series of annular grooves upon the ribbed roll, it is possible to corrugate the wire within the sheet. The heated wire being pliable, it will yield only at the points where it receives pressure, and may, accordingly, be made to follow a waving, or any other desired, course in the sheet, as the outline of the periphery of the ribbed roll shall determine. Thus the wire is, so to speak, woven within the glass in such manner as to tie both wire and glass together.

The glass after it has been rolled is carefully annealed in a furnace of the usual construction (*Plate 6*). The wire embedded in the glass not only strengthens the sheet, but also prevents the particles of glass from breaking entirely away from the main sheet, while, on the other hand, the glass protects the wire against corrosion.

From the foregoing abstract, it will appear that the radically novel feature of Shuman's apparatus is the ribbed or

grooved roll, by which the wire netting is pressed to a predetermined depth into the glass whilst the sheet is being rolled, and, at the same time, is permanently fixed in position by the following smoothing rolls; and the scope of the process may be defined as rolling out a sheet of glass, pressing into it a metallic fabric, and finishing the sheet by pressure of a heavy roll or rolls, whereby the metallic fabric is permanently embedded therein; these steps constituting practically a single operation.

The pressure of the rolls in the later machines is about fifty pounds to the square inch; the distance from centre to centre of the ribs or grooves in the ribbed roll is one inch. It has been found that with grooves of this size, any wire mesh between one-fourth inch and three inches can readily be embedded. These sizes of mesh represent the extremes of the sizes employed. A smaller mesh would require a groove of different size.

The average temperature of the fused glass is about 3,000° F. It is stated that the glass may be rolled at about 2,200° F., although the higher temperature is evidently the better one.

The inventions of Mr. Shuman are in practical operation on an extensive scale at the works of the American Wire Glass Manufacturing Company, at Tacony, Philadelphia.

The works cover an area of one and one-half acres, and the plant at present consists of one main building, 300 x 100 feet, and two auxiliary buildings, each 20 x 150 feet. The glass melting plant is an eight-pot Siemens regenerative furnace of the latest design and capable of melting ten tons of glass per day. The fuel used is gaseous, furnished by three Wellman gas producers. There are twelve annealing ovens of the Belgian type for tempering the glass sheets immediately after the wire has been inserted, and to these the glass is carried in a tray. These annealing ovens are heated by the Aërated Fuel Company's system using crude petroleum.

The steam plant consists of one fifty horse-power Babcock and Willcox, and one fifty horse-power upright, boiler. All mixing and handling of glass is done by machinery.

There are three sizes of rolling machines at present installed; two, capable of rolling sheets up to 24 x 84 inches; two, capable of rolling up to 30 x 84, and one machine capable of producing sheets as large as 54 x 144 inches.

Machinery has been introduced for handling the product wherever it could advantageously be applied. Thus, all the waste material is removed by tramways, and all cars and wagons are loaded from overhead tracks. The waste ends and imperfect sheets are utilized by separating the glass from the wire by means of special bending rolls. The glass broken off is returned to the furnace and the wire, wherever practicable, utilized for other sheets. With the experience now gained in the operation of the plant, it is stated that the percentage of defective sheets made is so small that it does not enter as a factor in the cost of production.

The rapidity with which sheets are made varies with the thickness. With three-sixteenths inch, the time of rolling is eighteen seconds; with one-fourth inch, twenty-five seconds; with three-eighths inch and over, thirty-five seconds. The capacity of the plant is 5,000 square feet per day of all sizes, and it is stated that the demand for the product has been large enough to keep the works fully occupied.

With its present facilities, which, it has been stated, will be extended as the requirements of business demand, the company is now engaged in the manufacture of wired-glass sheets of any required dimensions up to 4 x 10 feet and from $\frac{3}{16}$ to 1 inch in thickness. It is manifest that there must be a limit beyond which it would not be prudent to increase the dimensions of sheets on account of their weight, and the risk of cracking in handling and transportation. The usual dimensions for skylight and roofing glass range from 10 x 20 to 30 x 84 inches. Sheets larger than 48 x 144 inches, therefore, will rarely be called for.

The objection that has been urged against the process because of the difficulty of cutting the sheets to desired dimensions is a real one, but to a great extent has been overcome. In the operation of cutting, the sheets are first scratched with the diamond, then broken across the cut,

PLATE 8.—View of interior of works, showing operations of cutting and trimming. (American Wire Glass Manufacturing Company, Tacony, Philadelphia.)

PLATE 9.—Showing the appearance of a finished sheet of wired glass. (American Wire Glass Manufacturing Company, Tacony, Philadelphia.)

when the ductility of the embedded wire readily permits, by bending slightly to and fro, a sufficient separation of the edges of the cut to allow a thin-bladed saw to be inserted, by which the wires are cut through with comparative ease. In nearly all cases, however, the demands of the trade are for standard sizes, which require no cutting beyond that necessary to trim the edges.

The rolling machines, it should be explained, are adjustable, in length, breadth and thickness, up to their maximum range, to correspond with the dimensions of the sheets to be produced. Thus, on the same machine, wired-glass sheets of any thickness, width and length, within certain limits, may be produced, by adjusting the strips on the table for the regulation of the width, and the collars on the grooved roll for thickness: the length is regulated by that of the sheet of wire to be embedded and the quantity of glass poured upon the table.

By this adjustability of the rolling machines, it will be seen that the necessity of having a separate machine for each size of plate to be made is done away with, and that the problem of rolling sheets of any desired dimensions is practically solved.

Another point of interest which is worthy of notice, in connection with the operative features of the Shuman process, is the preliminary preparation of the wire for the production of the higher grades of wired glass. This consists in first removing the oil or grease from the wire by treatment with a cheap solvent (such as benzine), then passing the wire under a swiftly revolving roll, provided with bristles, and finally beneath flannel buffing wheels, whereby the wire is thoroughly cleansed and polished. For the best grades of wired glass, a specially annealed steel wire is used, which, after the cleansing treatment, presents a white and brilliant surface.

The following claims of merit, made on behalf of the new product, appear to be substantiated, viz: When used for the skylights in railway sheds, the much greater strength of wired glass permits the use of thinner and larger sheets, thus reducing the weights in the roof. It is hail-proof, and

proof against vibration. The copper wire netting which is now required beneath such skylights to protect persons below from injury by the accidental falling out of glass, may be dispensed with, thus saving not only the cost of the guard, but also the cost of renewing such netting when weakened by corrosion. The increased strength of wired glass will enable it to support with safety great weights of snow, which occasionally prove destructive to skylights of the ordinary kind; and, even should it become cracked by reason of rough usage or by accident, the tension of the wires will hold the fractured portions together, and the efficiency of the sheet will not be notably impaired.

Worthy of mention also is the fact that the common skylight guarded with wire tacked on beneath is so difficult to clean that this important item is practically neglected, with the result that the glass in time becomes greatly obscured by accumulations of soot and dirt.

It is probable that there would be much less likelihood of the occurrence of fatal or minor accidents caused by persons falling through skylights of wired glass when it is properly set in its frame; also, stones and heavy articles falling on such glass will often be arrested; and, on account of the time and trouble entailed in cutting through it with the diamond and severing the wires, it would interpose a much more serious obstacle to thieves, than the plain, unguarded glass. These qualities commend the new product for use in show windows where articles of value are exposed. It is proposed for windows in warehouses and stables, machine shops, railroad shops, and it is also suggested as advantageous for partitions in buildings. For deck, port and cabin lights in vessels, the same reasons should ensure its serviceability.

Finally, it is suggested that in the form of large sheets of extra thickness, strengthened by one or more enclosures of wire netting, and properly supported in an iron frame, wired glass would afford an advantageous substitute for the round bull's eye and other small patterns at present largely used for pavement and vault lights. The wired glass could not only be made sufficiently strong for such service, but

would also admit much more light per square foot of area than the forms of lights in common use.

These claims appear to be well founded.

The members of the committee of investigation, having had the opportunity of examining this invention in the course of its practical development on the commercial scale at the Tacony Works, are fully satisfied that the mechanical elements of the problem have been admirably worked out; that the present mode of manufacture is simple, efficient and rapid; and that the quality of the product is good. In conclusion, they find that the process and machine of Mr. Shuman, not only represent a marked advance upon all previous efforts in the class of inventions to which they relate, but also that they meet for the first time in this branch of the arts, the requirements of a practically operative method and means of manufacture.

For the reasons herein stated, and because of the undoubted advantages of wired glass for those uses for which it is adapted, the Institute recommends the award to the inventor, Frank Shuman, of the John Scott Legacy Premium and Medal, for his machine and process for producing wired glass.

JOSEPH M. WILSON, *President.*
WM. H. WAHL, *Secretary.*

Approved, November 1, 1893.

H. R. HEYL,
Chairman of the Committee on Science and the Arts.

THE MANCHESTER SHIP CANAL AND ITS MORAL.*

BY PROF. LEWIS M. HAUPT, C.E.

[*A paper read before the Franklin Institute, December 20, 1893.*]

The corporation of Manchester, England, has just completed a ship canal, thirty-five and one-half miles in length, at a cost of $75,000,000. It was officially opened on the seventh of this month (December), after about six years of work, and it has justly engaged the attention of the engineering and commercial world as to its *raison d'être*.

The justification for this expensive structure arose from the physical and trade conditions of the locality which were believed to be injuriously affecting the manufactured products of the interior towns in the west of England, and restricting their markets by the high tolls required to reach the world's highway, the ocean.

This canal, therefore, unlike many others, was not built to reduce distance so much as to reduce rates, by bringing the ocean into direct competition with the railroads and the large canals already existing between Liverpool and Manchester. It furnishes a striking illustration of what an enterprising English manufacturing town will do to protect itself from injurious competition. The money contributed to this work was a *revenue for protection* against the excessive harbor dues of Liverpool, the cost of extra handling and the heavy railway charges.

Manchester evidently has invested a very large sum to escape the discriminations of Liverpool and secure the privilege of fixing her own port charges. The interest on this capital at four per cent. is $3,000,000, and it is believed to be a good investment for there are over 40,000 shareholders, thus evincing the great confidence of the public in

* Much of the information stated in this paper is derived from the report of Thos. Monro, C.E., to the Canadian Government.

the enterprise. It is estimated that the revenue from the 4,500,000 tons of prospective traffic will pay four per cent. on the investment. This would make the charge about sixty-six cents per ton—for both transit and storage—a very low rate on this comparatively limited tonnage. This does not include the cost of maintenance and operation but only interest. A better idea of the financial problem may be obtained by taking any article of the raw material and comparing the cost to Manchester via Liverpool, with that via the canal. Thus, cotton per ton is taxed as follows:

	s.	*d.*
Dock and town dues,	3	0
Master porterage,	1	3
Quay attendance,	1	0
Carting to rail,	1	3
Railroad or canal freight,	7	2
Total,	13	8

Whereas, by ship canal, we have:

	s.	*d.*	
Canal tolls,	4	3	= $1 06
Landing charges,	1	0	
Wharfage charges,	1	9	
Total,	7	0	

or about fifty per cent. less. The saving on one ton of cotton being $1.66. On sugar, the Liverpool charges are $4.47 per ton. On tea, the Liverpool charges are $4.54 per ton. The saving on sugar is $2.81 and on tea $2.40.

The manufactures of Manchester and vicinity would, therefore, save over fifty per cent. on the cost of transportation of these articles for this distance of thirty-five and one-half miles. The saving on wool is $2.16; on bacon, $2.10; on canned meats, $2.35; on wheat, $1.77; on petroleum, $2.12; on tallows, $1.91; on iron ore, $1.02, and on timber, $1.16. If there were no economies effected by this canal it would never have been built.

These, then, are a few of the reasons for the construction of this canal in the face of a bitter, organized and wealthy opposition and of unusual physical difficulties.

THE OPPOSITION.

As might have been expected, for it is incidental to all great works, this enterprise was strenuously opposed from its inception, both by the Dock Board and Corporation of Liverpool, and the various railway companies interested. About $750,000 were spent by its promoters in securing the necessary legislation. Its construction affords another proof of the fact that no railway can compete with a large canal in the cheap carriage of low grade freights.

It is stated that the famous Bridgewater Canal (which this one intersects) and on which barges of only fifty tons capacity are used, carries 60.000 tons of traffic per mile per annum, whilst the average of the railways of England is only 17,000 or less than one-third. It pays a larger dividend also than any railway in the country and has recently been bought by the Manchester Ship Canal Company, as a feeder, at a cost of $8,750,000.

The Leeds and Liverpool Canal, which is still independent of railroad control, pays an average dividend of over eighteen per cent. while the income from the Bridgewater Canal is said to be thirty-four per cent. on the above cost.

CONSTRUCTION.

The work was commenced November 11, 1887, by Mr. Thomas A. Walker, contractor, who expected to complete it in three years for a sum not to exceed $28,750,000 and $4,014,680 for land damages, but his untimely death, coupled with strikes, storms and the delays incidental to corporate management, conspired to postpone its completion and increase its cost.

On the fourth of February, 1891, it was found that the funds were practically exhausted and an appeal was made to the corporation of Manchester for advances, was promptly and cordially responded to, and the work was continued by the Directors. Thus this enormous work, involving 46,000,000 cubic yards of excavation and many expensive auxiliary works, to provide for the maintenance of existing traffic, was completed in six years, at a cost of about $2,000,000 per mile.

Beginning at the lower end, at Eastham, six miles above Liverpool in the Mersey, there are three locks placed side by side of different sizes to facilitate traffic. No. 1 is 600 x 80; No. 2 is 350 x 50, and No. 3 is 150 x 30, all having a lift of 9 feet 6 inches. This admits vessels to the reach extending through and beyond the estuary of the Mersey to Latchford, twenty-one miles distant. Here a second lift of 16 feet 6 inches is made by two locks abreast, No. 1 being 600 x 65 feet in size, and No. 2, 350 x 45. Thence it is seven and one-half miles to a third lift of sixteen feet at Irlam, where are found two more locks of the same dimensions as above. Two miles further brings us to the Barton locks of fifteen feet rise; otherwise, a duplicate of the preceding. Thence it is three and one-half miles to the Mode Wheel lift of thirteen feet with similar lockage and thence one and three-fourths miles to the landings at Manchester. This last reach constitutes the harbor and docks.

In addition to these eleven locks there are extensive quays at Warrington and Manchester, numerous sluices to provide for the movements of tidal and storm water, various swing and high level bridges, and one canal turn-table, with various other works of lesser magnitude.

STATISTICS.

Canal trench, minimum (120 x 26) (length miles), . . .	35½
Total lift (feet), ...	70
Total excavation (cubic yards), ...	46,000,000
(of which 10,000,000 was sandstone rock.)	
Straight lines (miles), ...	20½
Curved (miles), ...	15
Minimum radius at Runcour (feet), ...	1,980
Number of railroad, high level, bridges (75 feet), . . .	5
Total length of railway diversion (miles), ...	11¼
Road bridges, high level (75 feet), ...	2
Road bridges, swing (120 feet span), ...	6
Aqueduct bridges, swing, at Barton (290 feet span), . .	1
Area of Manchester docks (water acres), ...	114
Area of Manchester docks, quay space (acres), . . .	152
Length of Manchester quay walls (miles), ...	5¼
Warrington docks (acres), ...	23

At Partington, canal widened and hydraulic coal tips introduced.

STATISTICS—*Continued.*

Time of transit including lockage (hours),	10
Number of bricks required,	70,000,000
Number of yards of concrete,	1,250,000
Number of yards of brick work,	175,000
Number of yards of masonry,	220,000
Steam excavators employed,	100
Locomotives (in 1890),	173
Wagons and trucks (capacity, 4 cubic yards),	6,300
Miles of railway (standard gauge) (miles),	223

The rate of excavation varied from 750,000 to 150,000 cubic yards per month; 2,400 yards per day of ten hours have been removed by one dredge. The German machines would average 2,000 yards per day, and the English 700.

Number of steam cranes,	194
Number of portable and other steam engines,	182
Number of steam pumps,	209
Tons of coal consumed, per month,	10,000
Value of the plant owned by Mr. Walker,	$5,000,000
Average cost of earth excavation (cents),	30
Number of men and boys employed, about,	20,000

The hydraulic turn-table for carrying the Bridgewater Canal is a large iron caisson, 234 feet long, 25 feet wide and 6 feet deep, having the ends closed by movable gates. A similar pair of gates also close the ends of the canal so that when a ship is passing through the Manchester Canal, the Bridgewater Canal is cut in two, and a section of it swung around as in an ordinary turn-table.

When full of water it weighed 1,450 tons. It is supported on sixty-four conical rollers, each 2 feet 8 inches long, operated, as are all the swing bridges and lock gates, by hydraulic machinery.

PHYSICAL DIFFICULTIES.

From this general description it will be seen that the physical difficulties were of no mean order. A tide of about twenty-seven feet; a heavy embankment through the estuary of the Mersey; a lift of over seventy feet; cuttings exceeding sixty-six feet in depth, and in one instance an average depth of fifty-five feet extending for one and one-half miles:

the cutting of the main river and its tributaries at numerous points, and the maintenance of the drainage systems during construction; the building of siphons under the canal in soft clay below sea level; the maintenance of traffic on the railways, canals and highways; the damages by floods and land-slides, which several times filled large sections of the works with mud and water, and which, below the locks at Latchford, rose forty feet and inundated the works for miles; the building of numerous sluices and rivers; and the long haul to the waste banks all bear tribute to the zeal, energy and perseverance of the contractors and the promoters of this great economic project so happily completed.

THE MORAL.

The laws governing the movements of trade are the same throughout the world. Commerce, like other streams, seeks the line of least resistance, and that is the one involving least time and money between terminals. A line which embodies a saving of distance, time, risks and cost has therefore the essential elements of success to insure it, and a nation or people having such opportunities, and failing to improve them must expect to suffer in the race for commercial supremacy.

To apply the lesson to ourselves we have only to remember that up to the opening of the Erie Canal in 1826, Philadelphia enjoyed the proud distinction of being the first commercial city of the United States. This was due largely to the energy of one man, Stephen Girard, whose benefactions still bless the community.

To-day, the waterways that formerly contributed so largely to our commercial and industrial growth, are almost abandoned, and we find ourselves over 100 miles from the highway of commerce, with but one circuitous avenue to reach it.

Like the tides our commerce must now ebb and flow through the Delaware capes, but it is a simple, cheap and economic physical problem to cause a continuous current past our doors, and to divert the track of the coastwise and

much of the foreign commerce from the outer dangerous passage to the inner safe and productive one by a ship canal across the girdle of New Jersey, and another across the neck of the Delaware—Maryland peninsula. If there were need for the Manchester Canal built by a corporation at the great cost of $75,000,000, and in the face of serious physical difficulties and vested interests, certain it is that there is far more reason for the enlargement of the Atlantic coast canals, under much more favorable conditions, at much less cost, and with a far greater tonnage in sight.

As the engineering and physical features of these projects have hitherto been presented to the Institute, I will only recapitulate that the line across New Jersey would be thirty-three miles long, having six locks with a summit level fifty feet above tide; the highest point on the divide being but seventy-six feet above tide or twenty-six above the summit level, while the drainage basin for its supply covers over 300 square miles.

If made large enough to carry the largest battleships or cruisers, its cost would probably not exceed $25,000,000.

In this connection it may be well to note that our defensive naval armament has cost the country over $65,000,000 in the last ten years and $12,000,000 more are appropriated, but unexpended.

The construction of these two canal links, which are essential to the successful use of this magnificent naval equipment, at a total cost of (say) $32,000,000, or less than one-half that of the vessels, will quadruple their efficiency by giving them control of the strategic lines of defence along the coast.

To quadruple the effective force of our navy at one-half its cost is a proposition which must demand consideration as an economic problem.

Again, from the humane standpoint, the necessity for this work asserts itself; for during the past fiscal year between Massachusetts and North Carolina there have been 214 wrecks, of which fifty-nine were total losses. The value of the property wholly destroyed was $1,146,395, or twenty-nine per cent. of the value risked. Of the 1,404 lives risked

only twenty-four were lost and most of them in the Fourth District, or on the coast of New Jersey.

This total loss for one year in this stretch of coast, if capitalized at four per cent., would represent $28,659,875, or a sum almost sufficient to canalize this entire route for deep draught vessels. Will any one say that it is not wiser to spend this money in saving life and avoiding the risks than in permitting it to be buried in the depths of the sea?

There are many other reasons—political, social. commercial and financial—why this work should be inaugurated, but I must refrain from lack of time. The project is old, dating back to 1812, but the times were immature and the machinery not available. Now they seem to be ripe, but still the canals await the "Touch of a vanished hand and the sound of a voice that is still."

The Executive Departments do not move because Congress is indifferent and Congressmen are inert because their constituents are not awake to the importance of the measure. The citizens do not urge it because there has been no concerted action to direct public attention to its importance and crystallize the movement, but when this shall have been done by such instrumentalities as your learned societies—the Franklin Institute, the American Philosophical Society, the National Board of Trade, the Trades League, the various engineering societies, commercial clubs, trade associations and kindred organizations—then like the familiar rhyme in Mother Goose, "When the mouse begins to gnaw the rope," the whole machinery will be set in motion, resolutions and petitions will flow into Congress; Congress will make the necessary appropriations; the Executive Departments will make the surveys and under the continuous contract system the canals will soon become an accomplished fact, and the world will wonder why it was not done long before.

Would it not be in accord with the honorable record of this distinguished organization if the Franklin Institute would press the button, connecting with the wires to Washington and start the machinery?

SLAG CEMENT EXPERIMENTS.

By R. W. Mahon.

[*Read by title at the meeting of the Chemical Section, October 17, 1893.*]

The manufacture of slag cement abroad has become a considerable industry, works having been established in a number of European countries. Probably the greatest development has been reached in Germany. In 1892, it was stated in a communication to the Architectural Association of Berlin, that there were then, in that country, ten slag cement factories with an annual production of 600.000 tons.

The blast furnace slags used in the following experiments were complex basic silicates of lime, alumina and magnesia, with a little ferrous oxide and alkali, and containing a small percentage of sulphide of lime. Furnace slag is somewhat cementatious; this property increasing with the contained lime. The cementing value of slag is greatly increased and hydraulic properties imparted to it by running it molten into water. This operation granulates the slag, but except for the possible elimination of a minute quantity of sulphur as sulphuretted hydrogen, leaves its chemical composition unchanged. Some change has, however, taken place in the molecule, to account for which various explanations have been offered. Thus it has been advanced that the change is analogous to that which sulphur undergoes when fused and quenched; an altered molecular condition being preserved.

Le Chatelier has suggested and presented calorimetric experiments in confirmation, that granulated slag contains the whole of the energy which appears as heat if the same slag be allowed to crystallize instead of being granulated; and hence that its atoms have greater power of combination. Whatever the change may be, the granulated slag, it is certain, possesses new properties, and can unite with calcium hydrate in certain proportions, when water is added, forming in the case of some slags a valuable cement.

Some time since the Maryland Steel Company entrusted the writer with an investigation of the slag from their blast furnaces, to determine its value for cement making. The experiments here recorded are laboratory experiments and of a preliminary character, preliminary to further laboratory experiments, and also to experiments on the manufacturing scale.

Attention has been here given, first to determine whether it were possible from these slags to make cement at all or not. This point having been decided in the affirmative, it was next sought to determine the range of slag available.

This company uses Mediterranean ores, and an ore mined in the island of Cuba. Their limestone comes from a point near the city of Baltimore. It is possible to divide this stone into two varieties: one containing a low percentage of magnesia, and one a higher percentage. It would be quite possible to reject the high magnesia stone at the quarries. This might prove useful in two ways, besides lowering the magnesia, and so increasing the safety of the cement, it would raise the percentage of lime. It seems probable that slag containing more lime, replacing magnesia, would furnish cements of greater strength. This limestone when in rather large crystals, either compact or loosely coherent, and of various colors and appearance, as white, blue, milky, etc., is invariably low in magnesia. Whereas the compact variety in small crystals and of various colors is invariably high in magnesia. Thus a series of magnesia determinations in these two varieties resulted as follows:

MAGNESIA PERCENTAGES.

Large Crystalline Variety.	*Compact Variety Composed of Small Crystals.*
2·48	13·44
0·57	17·55
1·44	14·66
trace	16·16
trace	17·58
0·90	13·15
1·19	
trace	

TABLE OF THE SLAGS USED.

Slag.	Silica. SiO_2.	Alumina. Al_2O_3.	Iron. Fe.	Lime. CaO.	Magnesia. MgO.	Sulphur. S.
1	35·00	11·17	0·51	46·40	4·68	1·23
2	34·30	14·69	0·71	44·50	3·60	1·76
3	33·80	15·19	0·71	44·70	—	2·21
4	33·50	15·81	0·92	43·36	4·25	2·48
5	33·30	12·12	0·41	49·00	4·97	—
6	32·50	17·80	0·10	46·00	2·81	2·54
7	32·50	15·92	0·41	47·20	—	2·24
8	32·00	19·20	0·10	45·50	2·16	2·30
9	32·00	12·19	0·92	46·50	5·76	2·07
10	31·80	14·77	0·51	45·90	4·50	2·23
11	31·00	18·80	0·10	43·90	2·70	2·16
12	31·00	17·51	0·20	45·00	3·24	—
13	30·00	17·00	0·10	47·50	—	2·38
14	29·90	16·94	0·81	45·00	2·52	2·33
15	29·10	15·70	0·10	48·80	4·03	2·31
16	28·68	15·08	1·00	47·20	3·96	2·46
17	25·30	2[illegible]·10	0·10	48·00	3·28	2·63
A	30·62	16·94	0·38	46·58	3·71	—

A is composed of equal parts of Nos. 6, 10, 12, 15 and 16. Each slag was granulated by running it molten into water, dried, ground on an iron plate, and sieved through an hundred mesh sieve. A series of cements was prepared from each sifted slag above described, by grinding it with slaked lime, in several different proportions. The slaked lime used was prepared in the following manner: Lime was slaked in a covered vessel by heating with more than twice the theoretical quantity of water required to hydrate it. After slaking it was removed, and allowed to dry spread out exposed to the air. When dry it was ground, and was then ready for use.

	Water. H_2O.	*Carbonic Acid.* CO_2.	*Silica.* SiO_2.	*Alumina.* Al_2O_3.	*Ferric Oxide.* Fe_2O_3.	*Lime* CaO.	*Magnesia.* MgO.
The slaked lime, . .	19·75	6·84	5·08	1·38	0·22	61·44	2·64

The following table contains a record of the tensile strength of test pieces of neat cement prepared from the slag cements, and from a number of bought cements for comparison. The bought cements are a German-Portland of the best quality designated German; an English-Portland of the best quality designated English; two domestic natural rock cements designated American Nos. 1 and 2. The first column of each set of three gives the cements, the second the tensile strength of the test pieces of neat cement expressed in pounds per square inch, the third the condi-

tions in which the test pieces were kept and the time before testing. Those test pieces of neat cement which were immersed had always hardened sufficiently for that treatment in one day, and usually in part of one day; except those which were made from three slags, viz: Nos. 2, 4 and 6, from No. 2 most markedly.

Meaning of abbreviations used in the table:

w.—water; m. a.—moist air; d. a—dry air; sl. l.—slaked lime.

These tests indicate that the best slags for cement making are low in silica and high in lime and alumina. Slags containing

	Per Cent.
Silica, ...	30 00 or less.
Lime, ...	47·50 " more.
Alumina, ...	17·00 " "

have given the best results. The best cements were made with slags Nos. 13 and 17. As the silica increases, and the lime and alumina decrease, the cementing properties of the slag diminish. Thus the cements made from slag No. 2 were inferior.

The principal table contains the tensile strength of a number of slags granulated, dried, ground and sieved, but without the addition of slaked lime. This material hardens very slowly and is of a sandy character. The test pieces can only be removed from the moulds after hardening for several days. In the case of No. 17 slag after twenty-eight days in moist air, the test piece was a hard mass, but still slightly sandy on the outside, and possessing a tensile strength of 235 pounds per square inch.

The principal table contains examples of cements made with the same slags, granulated and not granulated, and shows the value of granulation for imparting cementing properties.

Tensile Strength in Pounds per Square Inch.

100 Mesh.	150 Mesh.
196	177
158	235
160	185
190	235

Conclusive experiments on the value of finer grinding could not be made with the simple appliances at hand.

Four experiments of this kind are collected here, taken from the principal table.

FINENESS OF THE BOUGHT CEMENTS, USING 100 PARTS OF ORIGINAL CEMENT IN EACH CASE.

Cement.	100 Mesh.		150 Mesh.	
	Left on.	Passing.	Left on.	Passing.
German	20	80	30	70
English,	33	67	49	51
American No 1,	37	67	37	63
American No. 2,	24	76	60	40

Cementing two Bricks Together.—Pairs of bricks first saturated with water were cemented together with a mortar composed of cement one part and sand three parts, by weight. These were kept in the dry air of the laboratory for various periods, lying loosely, not with pressure upon them as in a wall. It was then attempted to tear them apart by hand. The only mortars failing to stand this test, showing want of power of adherence to a brick surface, after hardening in dry air, were those made from cements, from the poorer slags, with small proportion of slaked lime, when these were tested for short periods.

Although none of the bought cements show shrinkage in dry air, some of the slag cements undoubtedly have a tendency to shrink in dry air. These are the cements made from the poorer slags. In these experiments this shrinkage was noticed most markedly with cements made from No. 2 slag. On the other hand, the cements from the best slags show no shrinkage in dry air. Slag cements set slowly, and the cements from No. 2 slag have been found to be exceedingly slow setting.

Test pieces of the slag cements prepared in the course of these experiments, seem to reach their full strength slowly, and this applies especially to pieces immersed in water.

The hardness is satisfactory for cements from the best slags for pieces in dry or moist air. The test pieces hardened in water have not been entirely satisfactory in hardness, although frequently having a tensile strength of

Cement.
German, ...
English, ...
American No. 1, . .
American No. 2, .
Slag No. 4, . . 400 / Sl. l., ... 60
Slag No. 4, . . 100 / Sl. l., ... 70
Slag No. 6, . . 100 / Sl. l., ...
Slag No. 6, . . 100 / Sl. l., ... 10
Slag No. 6, . . 100 / Sl. l., ... 20
Slag No. 6, . . 100 / Sl. l., ... 30
Slag No. 6, . . 100 / *Sl. l., ... 30
Slag No. 6, . . 100 / Sl. l., ... 40
Slag No. 6, . . 100 / Sl. l., ... 50

Cement.	Tensile Strength.	Days in
g No. 8, . . 100 / l., ...	223	m. a. 28
g No. 8, . . 100 / l., ... 10	136	d. a. 28
	200	w. 28
g No. 11, . 100 / l., ...	Broke in	removing.
g No. 11, . 100 / ., ... 20	144	m. a. 28
g No. 11, . 100 / ., ... 30	166	m. a. 28
g No. 11, . 100 / l., ... 40	152	m. a. 28
g No. 11, . 100 / ., ... 50	146	m. a. 28
g No. 11, . 100 / ., ... 70	146	m. a. 28
g No. 12, . 100 / ., ... 20	113	m. a. 28
	122	d. a. 28
	160	w. 28
g No. 12, . 100 / ., ... 30	115	m. a. 28
	30	d. a. 28
	140	w. 28
g No. 12, . 100 / ., ... 40	163	m. a. 28
g No. 12, 100 / ., ... 50	182	m. a. 28
	192	w. 28
	70	d. a. 28
g No. 12, . 100 / ., ... 70	148	m. a. 28
	13	d. a. 28
g No. 13, . 100 / ., ...	Broke in	removing.
g No. 16, . 100 / l., ... 35	200	m. a. 24
	180	w. 29
g No. 16, . 100 / ., ... 40	106	m. a. 24
	120	w. 24
g No. 16, . 100 / ., ... 45	124	m. a. 28
	98	w. 28
Br g No. 16, . 100 / ., ... 50	114	d. a. 28
	106	w. 28
g No. 16, . 100 / l., ... 55	140	m. a. 28
	106	w. 28
g No. 16, . 100 / ., ... 60	97	d. a. 28
	105	w. 28
g No. 16, . 100 / l., ... 65	122	m. a. 28
	93	w. 28
g No. 16, . 100 / l., ... 70	108	d. a. 28
	104	w. 28
g No. 16, . 100 / ., ... 75	97	d. a. 28
	88	w. 28
g No. 17, . 100 / ., ...	235	m. a. 28
g No. 17, . 100 / ., ... 10	168	m. a. 28
	200	w. 28

Cement.	Tensile Strength.	Days in
Slag No. 10, . 100 / Sl. l., ... 35	107	m. a. 28
	108	w. 28
Slag No. 13, . 100 / Sl. l., ... 10	184	m. a. 28
Slag No. 13, . 100 / Sl. l., ... 15	198	m. a. 28
Slag No. 13, . 100 / Sl. l., ... 20	215	m. a. 28
Slag No. 13, . 100 / Sl. l., ... 25	353	m. a. 28
Slag No. 13, . 100 / Sl. l., ... 30	220	m. a. 28
Slag No. 13, . 100 / *Sl. l., . . . 30	266	w. 28
Slag No. 13, . 100 / Sl. l., ... 35	205	m. a. 28
Slag No 15, . 100 / Sl. l., ... 10	56	m. a. 1
	184	m. a. 28
	205	d. a. 28
	158	w. 28
Slag No. 15, . 100 / Sl. l., ... 15	80	m. a. 1
	200	m. a. 28
	185	w. 22
Slag No. 15, . 100 / Sl. l., ... 20	53	m. a. 1
	72	d. a. 1
	108	d. a. 1
	200	m. a. 26
	240	d. a. 28
	160	w. 28
Slag No. 17, . 100 / Sl. l., ... 15	200	m. a. 28
	265	w. 23
Slag No. 17, . 100 / Sl. l., ... 20	240	m. a. 28
	156	w. 28
Slag No. 17, . 100 / Sl. l., ... 30	210	m. a. 28
	375	d. a. 28
	253	w. 28
Slag No. 17, . 100 / Sl. l., ... 40	201	m. a. 28
	245	w. 28
Slag No. 17, . 100 / Sl. l., ... 50	176	m. a. 28
	200	w. 28
Slag No. 17, . 100 / Sl. l., . . . 75	265	d. a. 28
	132	w. 28
Slag No. 17, . 100 / ‡Sl. l., ...	49	m. a. 28
Slag No. 17, . 100 / ‡Sl. l., ... 30	76	m. a. 28
Slag No. 17, . 100 / ‡Sl. l., ... 40	50	m. a. 28
Slag A, ... 100 / Sl. l., ... 20	186	m. a. 28
Slag A, ... 100 / Sl. l., . . . 30	192	m. a. 28
Slag A, . . . 100 / Sl. l., ... 40	175	m. a. 28
Slag A, ... 100 / Sl. l., ... 50	113	m. a. 28
Slag A, ... 100 / Sl. l., ... 70	122	m. a. 28

* 150 Mesh,

Not granulated.

CEMENT.	Tensile Strength.	Days in
German	[illegible]8	m. a. 1
	103	m. a. 1
	310	m. a. 6
	355	m. a. 6
	403	m. a. 28
	385	d. a. 28
	433	w. 28
English	115	m. a. 1
	275	m. a. 6
	333	m. a. 28
	266	d. a. 28
	168	d. a. 28
	235	d. a. 28
	333	w. 28
American No. 1	45	m. a. 1
	72	m. a. 6
	109	m. a. 28
	88	d. a. 28
	79	w. 28
American No. 2	99	m. a. 1
	182	m. a. 6
	283	m. a. 25
	380	d. a. 25
	180	w. 25
Slag No. 4, . . 400; Sl. l., ... 60	170	m. a. 28
	60	d. a. 28
	136	w. 28
Slag No. 4, . . 100; Sl. l., ... 70	106	d. a. 28
	131	w. 28
Slag No. 6, . . 100; Sl. l., ...	Broke in	removing.
Slag No. 6, . . 100; Sl. l., ... 10	185	m. a. 28
	140	d. a. 28
	220	w. 28
Slag No. 6, . . 100; Sl. l., ... 20	126	m. a. 28
	230	d. a. 28
	240	w. 28
Slag No. 6, . . 100; Sl. l., ... 30	195	m. a. 28
	250	d. a. 28
	196	w. 28
Slag No. 6, . 100; *Sl. l. 30	177	w. 28
Slag No. 6, . . 100; Sl. l., ... 40	186	m. a. 28
	192	d. a. 28
	240	w. 28
Slag No. 6, . . 100; Sl. l., ... 50	126	m. a. 28

CEMENT.	Tensile Strength.	Days in
Slag No. 2, . . 100; Sl. l., ... 30	40	d. a. 28
	68	w. 28
Slag No. 2, . . 100; Sl. l., ... 35	166	m. a. 28
	75	d. a. 28
Slag No. 2, . . 100; Sl. l., ... 40	18	m. a. 28
	36	w. 28
Slag No. 2, . . 100; Sl. l., ... 45	14	d. a. 28
Slag No. 2, . . 100; Sl. l., ... 50	56	m. a. 28
	67	w. 28
Slag No. 2, . . 100; Sl. l., ... 55	125	m. a. 28
	84	w. 28
Slag No. 2, . . 100; Sl. l., ... 60	64	w. 28
Slag No. 2, . . 100; Sl. l., ... 65	104	m. a. 28
	91	w. 28
Slag No. 2, . . 100; Sl. l., ... 70	Went to pieces	in water.
Slag No. 2, . . 100; Sl. l., ... 75	Went to pieces	in water.
Slag No. 3, . . 100; Sl. l., ... 10	150	m. a. 28
	134	d. a. 28
	208	w. 28
Slag No. 3, . . 100; Sl. l., ... 30	210	m. a. 28
	225	d. a. 28
	250	w. 28
Slag No. 6, . . 100; Sl. l., ... 70	92	m. a. 28
	150	d. a. 28
	160	w. 28
Slag No. 7, . . 100; Sl. l., ...	Broke in	removing.
Slag No. 7, . . 100; Sl. l., ... 10	150	m. a. 28
	107	d. a. 28
	119	w. 28
Slag No. 7, . . 100; Sl. l., ... 20	77	m. a. 28
Slag No. 7, . . 100; Sl. l., ... 30	94	m. a. 28
	50	d. a. 28
	32	w. 28
Slag No. 7, . . 100; Sl. l., ... 40	115	m. a. 28
	240	d. a. 28
	245	w. 28
Slag No. 7, . . 100; *Sl. l., ... 40	185	m. a. 28
Slag No. 7, 100; Sl. l., ... 50	131	m. a. 28
Slag No. 7, . . 100; Sl. l., ... 60	240	m. a. 28
	150	d. a. 28
	190	w. 28
Slag No. 7, . . 100; Sl. l., ... 70	140	m. a. 28

CEMENT.	Tensile Strength.	Days in
Slag No. 3, . . 100; Sl. l., ... 40	240	m. a. 28
	193	d. a. 28
	238	w. 28
Slag No. 3, . . 100; Sl. l., ... 50	121	d. a. 28
	190	w. 28
Slag No. 3, . . 100; *Sl. l., ... 50	186	d. a. 28
	235	w. 28
Slag No. 4, . . 100; Sl. l., ... 30	158	m. a. 28
	59	d. a. 28
	103	w. 28
Slag No. 4, . . 100; Sl. l., ... 35	103	m. a. 28
	52	w. 28
Slag No. 4, . . 100; Sl. l., ... 40	158	m. a. 28
	104	w. 28
Slag No. 4, . . 100; Sl. l., ... 45	161	m. a. 28
	36	d. a. 28
	164	w. 28
Slag No. 4, . . 100; Sl. l., ... 50	180	m. a. 28
	93	d. a. 28
	159	w. 28
Slag No. 4, . . 100; Sl. l., ... 55	38	d. a. 28
	154	w. 28
Slag No. 8, . . 100; Sl. l., ... 20	235	w. 28
Slag No. 8, . . 100; Sl. l., ... 30	125	m. a. 28
	250	d. a. 28
	215	w. 28
Slag No. 8, . . 100; Sl. l., ... 40	140	m. a. 28
	260	d. a. 28
	200	w. 28
Slag No. 8, . . 100; Sl. l., ... 50	158	m. a. 28
	265	w. 28
	235	d. a. 28
Slag No. 8, . . 100; *Sl. l., ... 50	235	m. a. 28
Slag No. 8, . . 100; Sl. l., ... 70	180	d. a. 28
	250	w. 28
Slag No. 8, . . 100; Sl. l., ... 100	146	w. 28
†Slag No. 8, . 100; Sl. l., ...	Broke in	removing
‡Slag No. 8, . 100; Sl. l., . . . 30	Broke in	removing.
‡Slag No. 8, . 100; †Sl. l., ... 40	13	m. a. 28
‡Slag No. 8, . 100; Sl. l., ... 50	Broke in	removing.
Slag No. 10, . 100; Sl. l., ... 30	95	m. a. 28
	94	w. 28

CEMENT.	Tensile Strength.	Days in
	235	d. a. 28
	240	w. 28
Slag No. 10, . 100; Sl. l., ... 40	98	d. a. 28
	130	w. 28
Slag No. 10, . 100; Sl. l., ... 45	108	m. a. 28
	91	w. 28
Slag No. 10, . 100; Sl. l., ... 50	88	d. a. 28
	130	w. 28
Slag No. 10, . 100; Sl. l., ... 52	163	m. a. 28
Slag No. 10, . 100; Sl. l., ... 54	162	m. a. 28
Slag No. 10, . 100; Sl. l., ... 55	168	m. a. 28
	144	w. 28
Slag No. 10, . 100; Sl. l., ... 56	145	m. a. 28
Slag No. 10, . 100; Sl. l., ... 58	150	m. a. 28
Slag No. 10, . 100; Sl. l., ... 60	72	d. a. 28
	[illegible]17	w. 28
Slag No. 10, . 100; Sl. l., ... 65	152	m. a. 28
	125	w. 28
Slag No. 10, 100; Sl. l., ... 70	82	d. a. 28
	121	w. 28
Slag No. 10, . 100; Sl. l., . . . 73	145	m. a. 28
	126	w. 28
Slag No. 15, . 100; Sl. l., ... 30	96	m. a. 1
	95	d. a. 1
	98	d. a. 1
	235	m. a. 28
	120	w. 28
Slag No. 15, . 100; Sl. l., . . . 40	98	d. a. 1
	144	m. a. 26
	245	d. a. 28
	208	w. 28
Slag No. 15, . 100; Sl. l., ... 50	96	d. a. 1
	150	m. a. 26
	200	w. 28
Slag No. 15, . 100; Sl. l., ... 70	70	d. a. 1
	156	m. a. 26
	240	d. a. 28
	150	w. 28
Slag No. 15, . 100; Sl. l., ... 100	195	m. a. 28
	140	d. a. 28
	144	w. 28
Slag No. 16, . 100; Sl. l., ... 30	250	d. a. 24
	198	w. 24

CEMENT.	Tensile Strength	Days in
Slag No. 8, . . 100; Sl. l., ...	223	m. a. 28
Slag No. 8, . . 100; Sl. l., ... 10	136	d. a. 28
	200	w. 28
Slag No. 11, . 100; Sl. l., ...	Broke in	removing.
Slag No. 11, . 100; Sl. l., . . 20	144	m. a. 28
Slag No. 11, . 100; Sl. l., ... 30	166	m. a. 28
Slag No. 11, . 100; Sl. l., ... 40	152	m. a. 28
Slag No. 11, . 100; Sl. l., ... 50	146	m. a. 28
Slag No. 11, . 100; Sl. l., ... 70	146	m. a. 28
Slag No. 12, . 100; Sl. l., ... 20	113	m. a. 28
	122	d. a. 28
	160	w. 28
Slag No. 12, . 100; Sl. l., ... 30	115	m. a. 28
	30	d. a. 28
	140	w. 28
Slag No. 12, . 100; Sl. l., ... 40	163	m. a. 28
Slag No. 12, 100; Sl. l., ... 50	182	m. a. 28
	192	w. 28
	70	d. a. 28
Slag No. 12, . 100; Sl. l., ... 70	148	m. a. 28
	13	d. a. 28
Slag No. 13, . 100; Sl. l., ...	Broke in	removing.
Slag No. 16, . 100; Sl. l., ... 35	200	m. a. 24
	180	w. 29
Slag No. 16, . 100; Sl. l., ... 40	106	m. a. 24
	120	w. 24
Slag No. 16, 100; Sl. l., ... 45	124	m. a. 28
	98	w. 28
Slag No. 16, . 100; Sl. l., ... 50	114	d. a. 28
	106	w. 28
Slag No. 16, . 100; Sl. l., ... 55	140	m. a. 28
	106	w. 28
Slag No. 16, . 100; Sl. l., ... 60	97	d. a. 28
	105	w. 28
Slag No. 16, . 100; Sl. l., ... 65	122	m. a. 28
	93	w. 28
Slag No. 16, . 100; Sl. l., ... 70	108	d. a. 28
	104	w. 28
Slag No. 16, . 100; Sl. l., ... 75	97	d. a. 28
	88	w. 28
Slag No. 17, . 100; Sl. l., ...	235	m. a. 28
Slag No. 17, . 100; Sl. l., ... 10	168	m. a. 28
	200	w. 28

CEMENT.	Tensile Strength.	Days in
Slag No. 10, . 100; Sl. l., ... 35	[illegible]	m. a. [illegible]
	[illegible]	w. 28
Slag No. 13, . 100; Sl. l., ... 10	[illegible]	m. a. 28
Slag No. 13, . 100; Sl. l., ... 15	[illegible]	m. a. 28
Slag No. 13, . 100; Sl. l., ... 20	[illegible]	m. a. 28
Slag No. 13, . 100; Sl. l., ... 25	353	m. a. 28
Slag No. 13, . 100; Sl. l., . . . 30	220	m. a. 28
Slag No. 13, . 100; *Sl. l., . . . 30	266	w. 28
Slag No. 13, . 100; Sl. l., ... 35	225	m. a. 28
Slag No. 15, . 100; Sl. l., ... 10	56	m. a. 1
	184	m. a. 28
	205	d. a. 28
	158	w. 28
Slag No. 15, . 100; Sl. l., ... 15	80	m. a. 1
	200	m. a. 28
	185	w. 28
Slag No. 15, . 100; Sl. l., ... 20	53	m. a. 1
	72	d. a. 1
	108	d. a. 1
	200	m. a. [illegible]
	[illegible]	d. a. [illegible]
	160	w. 28
Slag No. 17, . 100; Sl. l., ... 15	200	m. a. 28
	265	w. [illegible]
Slag No. 17, . 100; Sl. l., ... 20	140	m. a. 28
	156	w. 28
Slag No. 17, . 100; Sl. l., ... 30	210	m. a. 28
	375	d. a. 28
	253	w. 28
Slag No. 17, . 100; Sl. l., ... 40	201	m. a. 28
	145	w. 28
Slag No. 17, . 100; Sl. l., ... 50	176	m. a. 28
	200	w. 28
Slag No. 17, . 100; Sl. l., . . . 75	265	d. a. 28
	[illegible]	w. 28
Slag No. 17, . 100; ‡Sl. l., ...	49	m. a. 28
Slag No. 17, . 100; ‡Sl. l., ... 30	[illegible]	m. a. 28
Slag No. 17, . 100; ‡Sl. l., ... 40	50	m. a. 28
Slag A, ... 100; Sl. l., ... 20	156	m. a. 28
Slag A, ... 100; Sl. l., . . . 30	102	m. a. 28
Slag A, ... 100; Sl. l., ... 40	175	m. a. 28
Slag A, ... 100; Sl. l., ... 50	113	m. a. 28
Slag A, ... 100; Sl. l., . . . 70	122	m. a. 28

* 150 Mesh. † Sandy. ‡ Not granulated.

200 to 250 pounds per square inch after twenty-eight days.

Possibly a lengthened period of time would give test pieces of satisfactory hardness in water.

COMPOSITION OF THE BOUGHT CEMENTS.

Cement.	Silica. SiO_2.	Alumina. Al_2O_3.	Iron. Fe.	Lime. CaO.	Magnesia. MgO.	Sulphur Trioxide. SO_3.
German, ...	21·72	6·73	2·43	63·80	0·75	1·37
English, ...	22·40	8·64	2·03	61·50	1·36	1·40
American No. 1, . .	20·50	7·61	1·53	49·20	2·52	1·10
American No. 2, . .	31·56	11·90	3·78	37·10	1·55	3·05

The best results thus far reached, could probably be much improved upon, with increased facilities in the following ways:

Hotter granulation.

Finer grinding.

Slaking under pressure.

More intimate incorporation of the sifted slag and slaked lime.

By using slags and slaked lime made from selected stone.

By using slags slightly higher in alumina.

SUMMARY.

Slags low in silica and high in lime and alumina are best suited for cement making.

Examples.—

Silica. SiO_2.	*Lime.* CaO.	*Alumina.* Al_2O_3.
25·30	48·00	20·10
30·00	47·50	17·00

The best cement made from such slags is prepared by the addition of about twenty-five parts of slaked lime to 100 parts of slag by weight.

Mortar made of one of cement to three of sand from such cement binds two bricks firmly together, even in the dry air of the laboratory. Test pieces of such mortar, hardened one day in air and twenty-seven days in water compare favorably with such mortar for good bought cements. Neat cement test pieces from the best slags show

no shrinkage in the moulds in dry air. These cements set slowly. Their hardness is satisfactory. By far the most complete set of comparisons made was the study of tensile strength at twenty-eight days, of neat cement test pieces, one square inch in cross-section, hardened in dry air, moist air and water, both for slag cements and bought cements.

Four examples, selected from the principal table of tensile strain after twenty-eight days follow.

They are the English Portland and the American natural rock No. 1; both in extensive use in this country, and the best two of the slag cements.

Cement.	Tensile Strain.	Kept in
English,	266	d. a.
	333	m. a.
	333	w.
American No. 1,	88	d. a.
	109	m. a.
	79	w.
Slag cement,	375	d. a.
	210	m. a.
	253	w.
Slag cement,	353	m. a.

BALTIMORE, MD, September, 1893.

EXAMINATION OF SPRING WATERS IN FAIRMOUNT PARK.

BY REUBEN HAINES.

[*Read at the stated meeting of the Chemical Section, January 16, 1894.*]

I have recently made a partial examination of the numerous spring waters that exist within the limits of Fairmount Park, determining chiefly the chlorine and nitrates. Three shallow pump wells not situated close to dwelling houses are also included. In both the East and West Parks the series proceeds northwards from Girard Avenue. The results are stated in parts per 100,000.

EAST FAIRMOUNT PARK.

	Chlorine.	Nitrogen in Nitrates.
(1) Spring in stone pavilion, Fountain Green, ...	·480	·166
(2) Stone fountain spring west of No. 1, near railroad, . .	·425	·140
(3) Dip spring at roadside, close to bridle path, ...	·536	·280
(4) Pump well at Rockland, east side of drive, ...	·930	·330
(5) Dip spring, east of Ormiston, ...	1·030	·150
(6) Pump well, Edgley, on grass plot east side of drive, .	·225	—
(7) Dip spring, south of Strawberry Mansion, ...	·380	·100
(8) Fountain on stone steps from Strawberry Mansion to the River Drive, ...	1·330	·500
(9) Fountain on River Drive at foot of steps from Strawberry Mansion, ...	1·265	—
	1·350	·425

Nos. 1, 2, 3, 4, 6 and first sample of No. 9 were collected October 18, 1893.

Nos. 5, 7, 8 and second sample of No. 9 were collected November 27th.

A sample of No. 5 collected October 18th gave chlorine ·93 parts per 100,000.

WEST FAIRMOUNT PARK.

	Chlorine.	Nitrogen in Nitrates.
(10) Pump well, Children's Play-ground, east side of drive,	·33	·12
(11) Dip spring in ravine southeast of Memorial Hall, . .	2·61	·48
(12) Dip spring at head of same ravine, close to the turn of the drive, ...	·61	1·00
(13) Spring enclosed in stone work on the road from Memorial Hall to the River Drive and opposite to the railroad, ...	·76	·44
(14) Dip spring beneath Lansdowne Bridge, southeast of Horticultural Hall, ...	·86	·22
(15) Dip spring near garden plots, southwest of Horticultural Hall, ...	·43	—
(16) Fountain spring in pavilion at Belmont Mansion, . .	1·64	·40
(17) Dip spring near south side of path to the recently abandoned Belmont Station, ...	·73	·15

All these samples from the West Park were collected October 27, 1893.

SPRINGS ON THE WISSAHICKON DRIVE.

The series begins at the first spring above Hermit Lane Bridge and proceeds in order up the stream.

	Date of Collection.	*Chlorine.*	*Nitrogen in Nitrates.*
(18) First spring above Hermit Lane Bridge, . .	June 10	·85	·54
	June 29	·85	·62
	Oct. 12	·91	·80
(19) Second spring, close to No. 18, ...	June 10	·70	·90
	June 29	·70	·97
(20) New stone fountain below Rittenhouse Lane,	June 10	1·05	·80
	June 29	1·13	·87
	Oct. 9	1·26	1·34
	Oct. 12	1·23	1·40
(21) Old stone fountain at junction of Rittenhouse Lane, ...	June 10	·99	·75
	June 29	1·08	·80
	Oct. 9	1·13	1·20
(22) Spring 400 yards above Rittenhouse Lane, .	April 16	·16	·09
	June 10	·15	.08
	June 29	·22	·08
	July 23	·22	—
	July 30	214	—
	Sept. 17	·183	—
	Oct. 9	·207	·10
(23) Spring nearly opposite "The Monastery," .	April 12	·53	·24
	June 29	·54	·30
(24) Spring between Allen Lane Bridge and Gorgas Lane, ...	April 12	·26	·18
	June 29	·29	.30
	July 23	·30	—
	July 30	·29	—
(25) Marble Fountain, three-fourths mile above Valley Green Hotel, ...	April 12	·25	·11
	June 29	.30	·13
	July 23	·27	—
	July 30	·30	—
(26) Small spring above tenth mile-stone, . . .	April 12	·24	·30
(27) Spring below Thomas Mill Road, ...	June 29	·30	·50
(28) Spring below Bell's Mill Road, ...	April 12	·33	·27
	June 29	·34	·57

Great differences in quality of the springs are apparent from the foregoing results. While one should scarcely venture an opinion as to their potability from determinations

only of chlorine and nitrates, yet it may be said that of all these springs No. 22 is unquestionably the purest at the present time. This water yielded no free ammonia or nitrites, and less than ·0020 parts albuminoid ammonia per 100,000. It agrees closely in chemical quality with perfectly uncontaminated spring water from wood-covered hills in Chester County, Pa.

Nos. 18, 19, 20 and 21 are, without doubt, contaminated by house drainage, the results of analysis being confirmed by inspection; but at present this sewage enters the spring water in a thoroughly oxidized condition, as shown by very low free and albuminoid ammonia and absence of nitrites. No. 8 and No. 9 probably originate from one source close to Strawberry Mansion. The high chlorine in these and in No. 16 at Belmont Mansion may possibly be caused by contamination with merely the contents of ice cream freezers at the restaurants attached to these popular resorts. In some of the other springs the contamination may not be of very recent date. Two of the wells appear to be purer than most of the springs in the East and West Parks.

The above results, however, indicate the desirability of a thorough sanitary inspection, accompanied by analysis, of all those springs showing the higher amounts of chlorine, namely, about 0·60 parts per 100,000 and upwards. This precaution appears particularly advisable for the reason that some of these springs are used for drinking by large numbers of people frequenting the Park. All the determinations of chlorine given were corrected for excess of silver nitrate required for the volume of liquid titrated.

A REMARKABLE ARTESIAN WELL WATER.

BY REUBEN HAINES.

[*Read at the stated meeting of the Chemical Section, January 16, 1894.*]

Some time ago an artesian well water was sent me, the character of which was so unusual that it is thought a record of the analysis would be of interest.

The well was situated in southern Alabama, about 300 yards from the Mobile River. Its depth was 685 feet, and an iron tube extended to the bottom through the sands, gravels and clays of the Gulf coast deposits. It was of the true artesian type, the water rising to the height of fifty feet above the surface, while the surrounding land had an elevation of but ten feet above sea level.

Two samples were sent, one in January, the second in May of the same year. Analysis of the first sample gave the following results. The water was of a dark brown color when viewed in a liter flask, but was tolerably clear and deposited only a slight sediment.

	Parts in 100,000.
Free ammonia,	0·3200
Albuminoid ammonia,	0·0120
Nitrogen in nitrates,	0·137
Chlorine,	79·767
Total solid residue,	171·50
Reaction of water,	strongly alkaline.

The solid residue from 100 cubic centimeters blackened slightly on ignition, giving an odor of burnt vegetable matter.

A partial analysis of the mineral constituents gave in parts for 100,000:

SiO_2 and Al_2O_3	Fe_2O_3	CaO	SO_3
2·75	0·95	1·35	0·38

The second sample was received on the twenty-eighth of May, having been collected about a week previously. Of

this a complete analysis was made, with results as follows:

COLOR (observed in tube two feet long)—very dark coffee brown.
ODOR (heated to nearly 100° C.)—unpleasant, odor of damp rotten wood.
TASTE (warm)—disagreeable, stale, brackish alkaline with organic flavor.
TRANSPARENCY—almost clear, a small amount of whitish sediment.

The sample was thoroughly mixed before analysis.

	Parts in 100,000.
Free ammonia,	0·6900
Albuminoid ammonia,	0·0740
Oxygen consumed (Kubel),	1·0892
Nitrogen in nitrates,	0·040
Chlorine,	99·80
Total solid residue (dried at 120° C.),	206·00

The solid residue gave on ignition a burnt woody or peaty odor. An animal odor was not perceptible.

The test for nitrites with sulphanilic acid and naphthylamine acetate was applied with rather uncertain result, except that there was possibly present only a small amount.

Heisch's test with sugar produced no change in the appearance of the water, indicating probable absence of phosphates.

The water concentrated by evaporation was strongly alkaline.

The sediment was composed of whitish flakes of vegetable matter of an indeterminate character. Numerous ciliated Infusoria—chiefly Paramæcia—were observed in the collected sediment.

The albuminoid ammonia was quite rapidly evolved, the first distillate of fifty cubic centimeters containing nearly three-fourths of the whole amount, when the distillation was conducted at the usual rate of fifty cubic centimeters in eight to ten minutes.

The mineral ingredients were found in this sample to be:

	Parts in 100,000.	*Grains per U. S. Gallon.*
Lime,	1·50	·87
Magnesia,	·64	·37
Potash,	2·90	1·69
Soda,	102·72	59·91
Chlorine,	99·80	58·20
Sulphuric acid,	·103	·06
Silica, iron oxide and alumina,	·85	·49

These ingredients probably existed in the following combinations:

	Parts in 100,000.	*Grains per U. S. Gallon.*
Potassium sulphate, ...	·22	·13
Potassium chloride, ...	4·40	2·57
Sodium chloride, ...	161·19	94·00
Sodium carbonate, ...	29·33	17·10
Calcium carbonate, ...	2·68	1·56
Magnesium carbonate, ...	1·34	·78
Silica, iron oxide and alumina, ...	·85	·49
	200·01	116·63

From the above results it will be seen that about ninety-seven per cent. of the mineral ingredients consist of sodium and potassium chlorides and sodium carbonate, the latter forming nearly fifteen per cent. of the total mineral matter.

On acidifying and warming the water, the organic matter separated as a light-colored flocculent precipitate which redissolved on addition of caustic or carbonated alkali. Excess of sodium carbonate perceptibly intensified the color of the solution as compared with that of the water made only slightly alkaline.

The more remarkable features of this artesian well water which are here to be noted are the very high color, approximating that of water from pools in bogs and swamps, and the enormous amounts of ammonia and of organic matter. Deep well and artesian waters are usually colorless and particularly free from organic matter, on account of the vast amount of filtration to which they are generally subjected. In uncontaminated ground waters ammonia is usually absent or present only in traces, since the ammonia existing in rain water as well as that resulting from natural slow decay of vegetation is converted in the soil to nitrate, which is to a large extent withdrawn through absorption by living plants. Yet deep artesian well waters occasionally contain considerable ammonia, which the great depth of the well, and other circumstances, show has no connection with sewage pollution. In some instances it has been referred to coal deposits which always contain nitrogen.

An instance of the occurrence of large amounts of free

ammonia in two shallow wells which were uncontaminated with sewage is mentioned in the *Report of the Massachusetts State Board of Health on Water Supplies, 1890*. These were two tubular driven wells, respectively, 17 and 44 feet deep and sunk 16 feet and 28 feet below the water-table, situated at Provincetown, on the northern extremity of Cape Cod. The following is abstracted from the analyses published in the above *Report for 1890*, pp. 274–75, in parts per 100,000.

	No. 1.	*No. 2.*
Free ammonia,	0·0246	0·0614
Albuminoid ammonia unfiltered,	0·0230	0·0244
Albuminoid ammonia filtered,	0·0216	0·0198
Color (0·01 mgm. NH_3 nesslerized in 50 cc. = 1)	3·30	2·80

The first of these wells was situated near a cranberry bog. The free ammonia is attributed to the decaying bodies of fish buried deep in the sand which forms the narrow extremity of Cape Cod. The deep brown color of these well waters is ascribed to a peaty layer under the sand. (*Report Mass. Board of Health, 1892*, p. 329.)

Reference may be made here also to the filter-galley, situated on the shores of the reservoir of the Wayland Water Works, Mass., the water of which although free from any contamination with sewage, always contains considerable free ammonia, while the water of the reservoir contains very little. This is attributed to imperfect filtration of the vegetable matter in the reservoir and its partial decomposition in the ground itself which is associated with iron oxide and the development of the fungus Crenothrix. (*Report of 1890*, p. 778, and *Report of 1892*, p. 325.)

Ammonia in natural waters may arise not only from decomposing animal matter, but also from the slow decay of vegetable substances which, like leaves, grass, etc., contain nitrogen. If the supply of oxygen is deficient, the process of oxidation of the nitrogen is arrested in its earlier stages and but little nitrate or nitrite is formed, especially in the presence of large excess of organic matter. Deep well waters are usually deficient in oxygen.

It appears probable that the greater part of the dissolved organic matter in the artesian well water from Alabama

is derived from a submerged peat bog or swamp, several hundred feet below the surface, overlaid with the diluvial drift, called "Orange-sand" by Professor Hilgard, and the alluvium of this region.

Under ordinary conditions the dissolved peaty matter occurring in *surface waters*, such as many streams and ponds in Massachusetts, does not appear to be prone to decomposition with attendant formation of ammonia. Normal uncontaminated waters of this class possess, according to Dr. T. M. Drown, a remarkably permanent character. The dark colored water of the Acushnet River, the water supply of New Bedford, is described as an instance of this fact.

It does not seem probable that so excessive an amount of ammonia as occurs in the Alabama well can be referred to decomposition of the vegetable substance alone, and that a portion of it, at least, must be caused by decomposition of the organic remains of fish and other marine animals, which have been, perhaps, partially preserved from decay through the antiseptic properties of peat. A quantity of bones and shells mingled with sand is stated to have been thrown up by this well during the interval between the analysis of the two samples sent me, which appears to indicate, in connection with the greatly increased free and albuminoid ammonia in the second analysis, that the above inference may be correct. The rapid evolution of the albuminoid ammonia and the readiness of the water to undergo putrefactive changes while standing in the laboratory also accord with this view. The animal odor, which would have been expected on ignition of the total solid residue, may have been masked by the large amount of vegetable matter and chlorides. The presence of species of Paramæcium is also a presumptive evidence of the existence of animal matter, for although these animalcules are especially abundant in decomposing vegetable infusions, they are regarded, when found in ponds and shallow well waters, as indicating probable contamination with sewage or other effete animal matter, and from a sanitary standpoint are, therefore, to be viewed with strong suspicion. The development of these Infusoria was no doubt incident

to the exposure of the water in a tank before the sample was bottled for analysis.

The excessive amount of sodium chloride in this well water may be attributed to the probable existence of saliferous beds somewhere in the vicinity. It is stated that during the Civil War "salt was obtained in considerable quantities from beds in the southwestern part of the State (Alabama), but the working of these has ceased to be profitable." (*Encyclopædia Britannica, American Supplement*, vol. i, "Alabama.") From the results of analysis it is manifest that the water has no direct connection with the sea, for its mineral composition is totally unlike that of sea water. The pressure of the water at the mouth of the well is of itself sufficient evidence that the water has an altogether different origin.

THOUGHTS ON COSMICAL ELECTRICITY.

By Elihu Thomson.

[*A lecture delivered before the Electrical Section, December 19, 1893.*]

Having been requested to speak to the Electrical Section of the Institute on some subject, it occurred to me that I might take the opportunity to present a few thoughts in the nature of speculations on the electrical relations of the earth and the heavenly bodies.

Where we have no definite knowledge we are forced to speculation, and often scientific speculation points the way to further advances in our theories. While speculation is not science, science is often benefited by speculative ideas; speculation is the result of imagination, science of investigation.

We know but little as yet regarding the actual facts in the study of cosmical electricity. We do know, however, that there is every reason to believe in the existence of electrical disturbances in space, and either proceeding from or concentrated by the bodies in the solar system.

We have, indeed, much to learn, and the difficulty of learning is the greater as we are called upon, in this case, to apply known principles to conditions comparatively unknown and difficult of conception by our mental powers. As an illustration, I may mention the paradox of the canals of Mars. Of all the planets, Mars is the one which appears to be like the earth, and, therefore, is the one, the phenomena of whose surface, it would seem, should yield most readily to interpretation. But we are puzzled at the very outset. So, also, it must be with a subject such as I have chosen for my talk to-night.

It is known that as we leave the surface of the earth and rise in the air, there is an increase of positive potential with respect to ground, such that on the top of the Washington Monument it may be 3,000 to 4,000 volts, and on the Eiffel Tower as much as 10,000 volts. On high mountains similar high potential differences are found. If the increase were equal to 1,000 volts for each 100 feet on the average, it would equal, at twenty miles altitude, about 1,000,000 volts, and from this it might be inferred that the conducting vacuous layer of rarefied air at great altitudes would possess a very considerable positive potential with respect to ground.

But just here we are confronted with a difficulty. It is not clearly proven that a pure gas, rarefied or not, can receive and convey a charge—solid or liquefied particles in it might readily do so, but there are considerations which seem to negative any assumption that gas molecules can themselves be charged.

If we imagine a charged drop of water suspended in air and evaporating, it follows, that, unless the charge be carried off in the vapor, the potential of the drop would rise steadily as its surface diminished and would become infinite as the drop disappeared, unless the charge were dissipated before the complete drying up of the drop by dispersion of the drop itself, or conveyance of electricity by its vapor. The charge would certainly require to pass somewhere and might leave the air and vapor charged. However this may be, the vacuum outside of our atmosphere is probably per-

fect, and, therefore, a perfect insulator. The ether itself appears to be the best insulator, or most nearly perfect non-conductor of electricity.

It is customary to speak of a charged body—this metal ball insulated in air, for example—as a thing by itself, but we well know that its capacity to receive a charge depends on the thickness of the surrounding dielectric, or the nearness of other conducting surfaces, such as the walls of the room, the floor and ceiling and other objects about it. The insulated ball is none the less one of the coatings of a condenser, the capacity of which depends on the thickness of the dielectric layer separating it from those objects or surfaces which form virtually the other coating.

It is doubtful then if a single body, in unlimited space, would be able to receive a charge of electricity, and it follows that even very large bodies like the earth and stars, separated as they are from one another by immense distances, cannot have much capacity. A comparatively small amount of electricity would give a very high potential in such a case.

It becomes an interesting question, just here, whether the fact that a charge resides only on the surface of a charged sphere or conductor, is due to attraction of opposite charges of sphere and surrounding objects, or to repulsion of like charge in the sphere, or to both. A simple consideration will show, I think, that it is due to both causes, and that lines of electrostatic induction joining oppositely charged surfaces and traversing the dielectric between them, are like lines of magnetic force, in that they both tend to spread laterally and also to shorten their paths. Their actual course, as is the case with the lines of magnetic force, will be determined by the resulting balance between both tendencies. Thus in *Fig. 1*, if two opposed surfaces *A B* are charged relatively, and then the surfaces be extended laterally, as indicated by dotted lines, and the extensions be of receding character, as shown, the charge will distribute itself over the added surfaces by virtue of the lateral spreading of the lines, while in doing this the actual length of the lines is increased.

Now, returning to the case of the earth, its capacity as a body insulated in space could not be very great, and a moderate amount of electricity in coulombs would give it a high potential. Viewed in another way, however, the earth may possess a much greater charge, or amount, of electricity. The solid earth itself is a conductor, the dense air around it a good insulator and dielectric layer, the rarefied air above a quasi-conductor in the sense that it can at small potential differences distribute a charge or convey a current, and the ether outside is a perfect insulator.

The earth may then possess the character of a huge conductor, the outer coating being rarefied conducting air, the inner coating, the ground and water surface and the dielectric the dense air between. The outer layers may

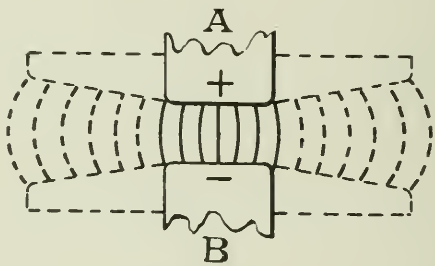


FIG. 1.

possess a potential, positive with respect to the earth's body, of, perhaps, as much as 1,000,000 volts.

Prof. H. A. Rowland has shown, however, that a moving charge is equivalent in magnetic effects to an electric current representing a similar transfer of electricity, and that a rotating charged air condenser produces that magnetic field which would be due to a current going in the direction of the moving changes on each plate. Applying this to the earth considered as a huge revolving condenser, *Fig. 2*, the dense air layer *A A A A* would become magnetized from pole to pole, and the velocity of the equatorial portion being so much greater than that of portions near the pole, would allow the magnetic lines to dip on each side of the equator in short-circuiting themselves through the solid earth *E*.

Moreover, the magnetic field so produced does actually correspond in direction of polarization with that which would be given when the outer coating *V V* is positive to the inner *E*, thus confirming so far the hypothesis which I have ventured to present to your consideration. It is merely a thought, and would need comparison of many data to give it a secure basis as a theory.

Any action which would disturb the charge of the con-

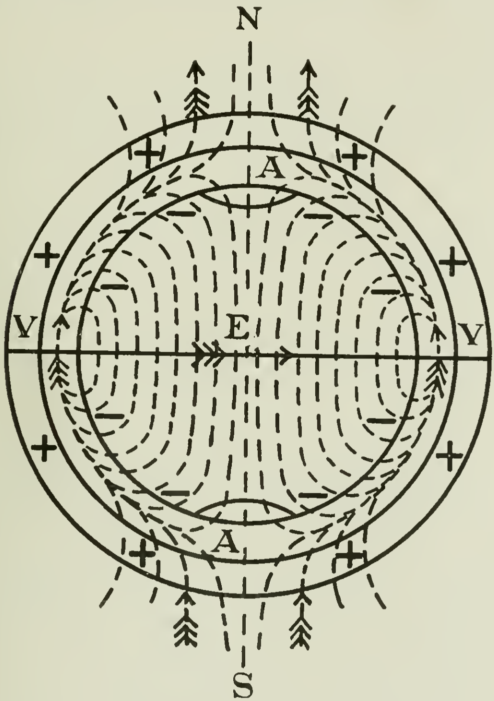


FIG. 2.

denser earth, would strongly affect the earth's magnetism and auroras especially would do so. They appear to represent a distribution of charge in the outer layers of the earth's atmosphere.

Assuming the earth to be a huge charged condenser, a thunder-storm might be brought about by a flow in the dense air dielectric, due to the presence of clouds of condensed vapor, extending to great altitudes. They may be

the auroral actions repeated in denser air, giving spark discharges, where in the aurora the diffused vacuum discharge only is seen.

The enormously high potentials exhibited in the thunderstorm may be secondary effects, due to coalescence of many minute drops of water charged to only moderate potentials, the reduction of surface raising the potential. It may in part be due also to evaporation of charged drops in some parts of the cloud, again reducing the surface and raising the potential.

The electrostatic induction of innumerable drops in a cloud, each drop possessing a like charge, gives virtually the effect of the possession by the cloud, considered as a whole, of a very much higher potential than is possessed by a single drop.

There must be some influence constantly at work to cause and maintain the positive potential of the higher layers of the atmosphere, for otherwise in various ways there would naturally be brought about an equalization of the charges of air and earth. Many theories have been proposed to account for the positive electrification of the air in its upper layers, and it may be that the condition is the result of a combination of causes rather than of any single cause. It is a legitimate thought, it appears to me, that the electrification may in large measure be due to influences outside of the earth itself. Let us assume a vast nebulous mass as having been the origin of the solar system by cooling and condensation, according to the nebular theory, and if for any reason that nebulous mass have a small charge or be at a potential difference with respect to other gaseous masses in space, the diminution of surface during shrinkage would gradually increase the potential of the charge, provided it could not escape through the surrounding ether. This charge would increase in potential until the finer particles on the outside of the mass were repelled outwards with a force equal to their centripetal tendency or gravity. A dispersion of such particles would ensue, and result in a fall of potential. The dispersion and accumulation of charges would occur periodically, while the hot mass of gas was shrinking and the par-

ticles sent off would be condensed vapors, liquid or solid, forming a charged cosmic dust proceeding in a radial direction from the central mass, just as the carbon sent out from a filament of an incandescent lamp leaves the filament radially after having condensed from vapor to solid carbon immediately at the surface of the filament, owing to the instant loss of the heat necessary to keep it vaporous.

Now the distance between the sun and a planet, such as the earth, is so great, that it is not probable that any considerable static—inductional effect could exist between them, even if they were at great differences of potential. On the other hand, electrified particles repelled periodically from the sun would reach the earth's atmosphere. It has been suggested that the coronal streams seen during total eclipses, particularly during the active or sun-spot period, may consist of electrified particles leaving the sun. If so, their lack of visibility, beyond a few diameters from the sun, would not forbid the assumption being entertained as a rational one, that the streams may pass outward indefinitely until they encounter some obstacle like the earth. But auroral displays on the earth are frequent only when the solar activity is greatest, when the coronal streams extend outwardly the farthest, and there appears to be a distinct connection between the presence of large spots on the sun's surface and auroral disturbances here.

Can we not consider that during an aurora the earth is passing through a coronal stream and developing, as it were, a secondary aurora, either by directly encountering in space the electrified particles from the sun, or by induction from streams of such particles near the earth's course?

Taking these thoughts in connection with the idea of the cause of the earth's magnetism presented above, it will be easy to understand why magnetic disturbances should be prominent during auroras. Taking also the fact that the sun is a charged body, and probably the planets also, it will be understood that some influence on the earth's condenser charge would exist, varying according to the positions relatively occupied by these bodies, and particularly of earth and sun. This in turn would give rise to magnetic variations,

such as the diurnal, annual and secular variations. It would account for the fact that the diurnal variations are greater when the earth is nearer the sun than when more remote,

My thought then, is, that the sun may be a charged body insulated in space, and, that owing either to a periodical accumulation of charge up to a certain critical potential, which would repel the outer particles into space and so relieve itself, or, to thermal disturbances occurring periodically during the cooling, the sun-spot period, or active period, recurs every eleven years, deforms the sun's outline, so far as the outer atmosphere is concerned, and raises the potential or the projecting parts to a degree to cause repulsion of particles; continuing until a certain discharge is effected, after which there is quiescence again.

During these actions the earth passes through, or near to, electrified streams and an aurora, or earth corona, is developed.

Concerning auroras, it would appear from observations of the great displays that the crown, or corona, seen in the zenith, is merely a view of bundles of streamers *on end*, and that the streamers in the north while nearly radial to the earth, are seen in perspective, rapidly changing their shapes and positions, while to the east and west are seen as comparatively stable but less defined streamers—an average view of great masses extending hundreds of miles and made up of innumerable changing streams of which the luminous effect is nearly steady. The grandest aurora which ever came under my personal observation was that of April, 1883, which reached its maximum between twelve and one o'clock. The whole horizon was in view as I was on top of a hill, and it is no exaggeration to say that the whole sky from north to south horizon and from east to west, was filled with auroral streams of wonderful coloring. The crown in the zenith was a marvellous display of changing light, changing positions, changing intensity and changing color. The streamers in the north were sharply defined like great bundles of luminous needles and seemed almost within reach. They changed rapidly, were remarkably brilliant and covered an angle from about 20° altitude

almost to the zenith. The stars, even of the first magnitude, could scarcely be seen, and although there was no moon, the time could easily be read on a watch, and the roofs of buildings, ten miles away, could easily be distinguished. I mention this aurora particularly because it showed in a most striking way the characteristics stated above, as indicating the radial position of the streamers. On no other theory could the zenith crown and streamers be seen simultaneously at places hundreds of miles east and west and many miles north and present substantially the same appearance.

It would appear that auroral displays are either much more rare in the southern hemisphere or absent altogether. Speaking on the subject with Dr. Gould, of Harvard University, he informed me that, although he had lived in Chili for fifteen years and was constantly on the watch for auroras, he never in that time saw a single display.

Now, if a discharge is taking place under critical conditions in a high vacuum, the relation of its path and direction to a magnetic field in the vacuum may determine the continuance or cause a stoppage of the discharge, according to the direction of magnetic polarization. Or, a stream of electrified particles may be deflected by a magnet, as shown in the well-known Crookes tubes. From this it might follow that the magnetism of the earth may be inhibitory to the discharge in the southern hemisphere and favorable to it in the northern, in which case the relatively greater frequency of the aurora *borealis* would be explained.

It has been found as a result of recent investigations that a negatively charged body will, if exposed to violet light, dissipate its charge to surrounding bodies, probably by sending off atoms, molecules or particles of its own substance negatively charged.

A positively electrified body placed in the neighborhood of a body maintained at a negative potential under violet light, is soon discharged by the negatively electrified particles coming to it from the negative body even when the positively charged body is not in the light. Whether this dissipation of negative charges would take place in the

ether itself, or in a very high vacuum, is, so far as I am now aware, not known. Evidently, however, such an action would have a very marked influence on the retention and distribution of charges on the earth.

If the sun's charge be positive and positively electrified particles are sent out in the coronal streams, it would be easy to understand that the outer earth charge might be kept up from the sun and that not only auroras, but thunderstorms also would be more frequent during periods of solar activity. Observations tend, I think, to show that such is the case.

Again, if the sun be a highly electrified body, might it not be possible that cometary masses may owe some of their illumination to redistribution of electricity as they approach towards and recede from the sun, or to encounter with electrified particles leaving the sun? Here, again, the radial direction of the comet's tail is suggestive, as are also the rapid changes which the comet undergoes.

And lastly, as a concluding thought, we may ask whether the phenomena of the sudden appearance of a star, which, after reaching great brilliancy, fades out in a few days or weeks, may not be referred to electrical causes, such as the equalization of charges on near approach of two bodies, attended as it must be with an enormous evolution of light, gradually fading away as the vapors cool after the discharge. Thus, some of the temporary stars may possibly be explained.

In conclusion, I beg to remind you what I have offered you here are only thoughts, not theories—which a careful comparison of all the facts may serve to confirm or to discredit. Objections may arise, but oftentimes what seems an insuperable objection disappears in the light of more complete knowledge and observation. It is true that the thoughts presented are not all new, and it is only the more gratifying when others may have arrived at similar guesses. Though generally busy with the practical side of electrical science, it is a source of pleasure sometimes to let one's thoughts have full play, even if the result be only a maze of speculation, some part of which may prove to be fallacious.

THE THEORY AND DESIGN OF THE CLOSED-COIL CONSTANT CURRENT DYNAMO.

BY HENRY S. CARHART.

[*A lecture delivered before the Electrical Section, December 26, 1893.*]

[*Concluded from p. 149.*]

The second method diminishes the overlap of the brushes as they are rocked forward. In the first place this has the effect of diminishing the time allowed for the reversal of the current, but it also diminishes the number of turns of wire in the coil or coils included between the two parts of each brush. The curtailed time interval increases the self-induction of each convolution of wire because it increases the rate of change of the current in the coil undergoing commutation; but this increase is counterbalanced by the diminution in the number of turns of wire short-circuited by the brush. Hence, the total self-induction during commutation remains not far from constant. When the brushes shift forward into a denser field, however, the diminution in the overlap decreases the number of turns of wire included between the pair of brushes composing either the positive or the negative, and so cuts down the total field induction in those coils during commutation to the amount required to suppress sparking. The overlap of the brushes must therefore be inversely as the induction in a coil under the brush in different parts of the field, for the presence of the pole of the armature at any point reduces the induction. This point is a complicated one and needs further experimental study.

But in the third class of machines the overlap of the brush is constant, and the field is not weakened by cutting out coils on small load. Neither are the pole faces cut away to produce uniform induction. Attention is given to the thickness of the pole pieces so as to avoid unnecessary crowding of the lines of force toward the central portions. It is also desirable to avoid thinning of the polar horns lest they become saturated. In the old Sperry machine, which

I have investigated quite carefully, each pole piece is cut quite in two. In fact, as is well known, the field has four cores. At the same time the horns or pole tips are rather blunt. But this machine shows the violent sparking when separately excited, when the brushes are far forward and the circuit through the armature is open. The induction round the armature is not uniform, but the sparking is small for any position of the brushes with the normal current. The brush bears on about three commutator segments. I refer to this machine as an illustration of the class, and not as a model of excellence. It is no longer built.

In this machine the induction to which a coil is subjected near the brush is not the same in different parts of the field, but diminishes as the brushes are rocked forward, the current being kept constant. With the exploring coil before described and the two extra brushes bearing on the insulated copper ring and the fibre collar with brass segment, respectively, the external circuit connecting the two small brushes was carried through a d'Arsonval galvanometer in shunt. The two extra brushes were attached to the two main brush holders, but were insulated therefrom. With the one making contact with the small brass segment two and then three commutator bars in advance of the upper main brush, the following deflections were obtained with the galvanometer from maximum to minimum load, the steps being about equal.

Deflections.	
Two Segments.	*Three Segments.*
26	63·5
24	56
22	49
20	41
18	34
16·5	32
13·5	
12·5	28
10·5	

The steps were not the same in the two series of observations. No trouble was found in obtaining a steady deflection of the galvanometer, the dynamo making about 1,200

revolutions per minute. The exploring coil was therefore subject to a diminishing induction near the brush as it moved forward with the brush toward the centre of the polar surfaces.

A similar series of experiments, made on an old Gramme machine of 3,000 or 4,000 watts capacity, built at the University of Michigan in 1876–77, gave a different result. The measurements were made by simply connecting a third brush to the upper brush holder and measuring the potential difference between it and the main brush in different parts of the field. The actual induction to which the armature wire is subjected in different parts of the field and at the same distance of two commutator bars from the main brush is thus measured.

The following table contains one series of observations:

Number of Observations.	Current in Ampères.	Potential Difference between Main Brushes.	Potential Difference between Main and Third Brush.
1	9·5	191	4·9
2	9·5	170	5·4
3	9·5	145	5·5
4	9·5	127	6·2
5	9·5	111	6·5
6	9·5	77	7·7
7	9·5	62	7·8
8	9·5	54	7·7
9	9·5	47	7·4

In this case the induction increases throughout the larger extent of the movement of the brush. But in this machine the knee of the characteristic curve is reached at about 13 ampères, while in the other machine it is found at seven ampères. The armature reaction in this older machine when run at ten ampères is relatively less than in the other one run with the same current. This is further evident from the fact that with the old Gramme run at ten ampères an increase in the current, due to lessening the external resistance, is always accompanied by an increase in the potential difference between the main and the third brush; while

with the ten-light Sperry machine, and others with similarly saturated field, an increase in the current when the brushes are fixed decreases the potential difference between the main and extra third brush. The reason is this: if the field is saturated, but not the armature, an increase in the current does not appreciably increase the field, but it does increase the armature reaction, and so cuts down the total potential difference between the main brushes as well as between one main and a third brush; while with an unsaturated field and a magnetically weaker armature, an incre-

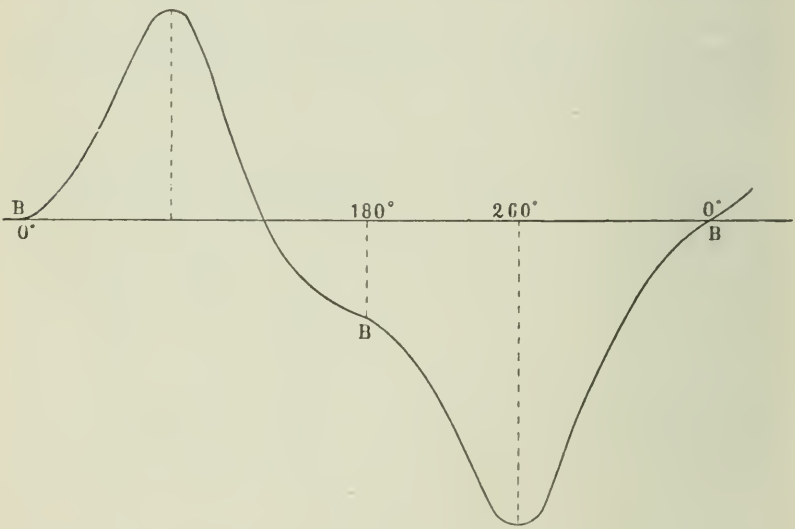


FIG. 2.

ment of the main current produces a greater increment in the field than in the armature reaction. With the same old Gramme machine run at about eighteen ampères, an increment in the current produces a decrease in the potential difference both between the main brushes and the main and third brush. The armature reaction then becomes relatively larger than the increase in the field magnetism. But this old machine exhibits perfectly the property of governing by rocking forward the brushes on a diminishing load, with no more sparking in one position of the brushes than in another.

Hence it is clear that for practically sparkless commutation it is not necessary that the induction *near* but *under* the brush shall be a constant. The effective means by which, with constant current, the brushes can be set in any plane round the commutator cylinder is the reactive effect of the armature. This fact is brought out quite clearly by plotting the integrated potential differences between the upper or positive brush and the third movable one as ordinates to a horizontal line. The data are the same as were employed to plot the first curve in *Fig. 1*. If *Fig. 2* is examined a decided flattening in the curve will be found at 180°, the position of the negative brush. The same flattening may be seen at 0°. All curves plotted with data obtained at different loads show the same diminution or stay of the inductive process near the poles of the armature. The armature at these points paralyzes the field. As the poles of the armature move around they sweep away the lines of force of the field, and only enough remain to produce an electro-motive force competent to offset the electro-motive force of self-induction and in addition cause the newly directed current to grow to its normal value as the coil passes out from under the brush.

This reactive power of the armature may be utilized to effect approximate regulation for constant current without brush-shifting. But for this purpose the load cannot be a maximum. The poles of the armature must be far enough forward to produce increase of magnetic leakage. As an example of what I mean, a forty-light machine had its brushes locked in such a position that it maintained thirty lights with ten ampères current. Ten lights were then cut off, and then ten more, with but small increase of sparking, and the ammeter showed an increase of current from ten to twelve ampères only. A change of two ampères is within limits possible for practical lighting. The machine was then completely short-circuited by placing a large bar of iron across its terminals without dangerous sparking. This means that the characteristic of the machine beyond the crown of the curve approached a vertical line, the ideal characteristic of an automatic constant current dynamo.

The conditions requisite for sparkless commutation of a constant current machine are therefore quite clearly defined. The self-induction of the short-circuited coils must nearly balance the field in all positions of the brushes. Both Mr. Esson, in a paper before the British Institute of Electrical Engineers,* and Professor Ryan, in a paper before the American Institute of Electrical Engineers,† lay down the conditions that the brushes must be kept under the pole faces in order not to enter the weakened field between the pole corners. And yet I have seen constant current machines working with the brushes beyond the extreme tips of the poles with no increase of sparking. I do not regard this condition as absolutely essential, since at maximum electro-motive force the brushes may be moved through a considerable angle without appreciable change in sparking.

Professor Ryan states, in his paper above referred to, that "the magnetizing force impressed by the field ampère-turns must be uniform at all points between the pole faces." This condition is favorable to sparkless commutation, but not essential. It has to do with the area of the sparkless position of the brushes for any given load. If the field is fairly uniform this area will be about the same in different parts of the polar faces; if the field is far from uniform sparkless commutation may yet be secured, but a smaller variation in the current will produce sparking than when the field is uniform, for the sparkless area on either side of the brush with a given external resistance is then much reduced. The region controlled by the armature poles is more limited in extent than when the field is uniform.

It follows that the single magnet type of field is not suitable for a constant current machine. This fact was remarked upon by Mr. Esson. For a two-pole machine the double magnet type is to be preferred. If then the iron is reduced at the back opposite the middle of the polar surfaces and the poles are thickened and rounded off rather blunt at the ends to prevent saturation, the field induction will be suffi-

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* *London Electrician*, March 21, 1890.

† *Proceedings*, Vol. VIII, p. 465.

ciently uniform without the necessity of resorting to the chopping away process applied to an English single magnet machine, described in Slingo & Brooker's *Electrical Engineering.*

Quoting again from Professor Ryan: "the air-gap is made of such a depth that the ampère-turns required to set up the magnetization through the armature, without current, and for the production of the highest electro-motive force that the machine will be called on to give, shall be a little more than the armature ampère-turns when it furnishes its normal current. Then as long as the brushes are kept under the pole faces, the non-sparking point will be wherever the brushes are placed. This will be the case whether the armature is or is not saturated." Again, "the impressed field ampère-turns are in excess of the armature ampère-turns by that amount which is just sufficient to produce a weak positive field that will reverse the current in the coil when its terminal bars at the commutator pass under the brush." This latter statement appears to be borne out by the data given, but the machine experimented upon was one giving a maximum of only thirty-five volts and twenty-two ampères, and its performance can scarcely be considered a sufficient guide for the design of machines required to furnish several thousand volts and a current of from 9·5 to ten ampères. Again, I have known a forty-light machine converted into a fifty-light without any change in the field whatever. The armature either contained more iron or was wound with a larger number of turns of wire. Both methods have been followed without effect on the sparking. The first method leaves the armature ampère-turns the same; the second increases them twenty-five per cent. If the relation pointed out by Professor Ryan holds in the first armature it cannot also hold in the second with such a material increase in armature-turns.

Further, if this relation does hold there still remains unanswered the question of relative cross-section of iron in armature and field. Shall the core of the armature be saturated or not? Mr. Esson says that 17,000 lines per square centimeter is the best practice in England for constant potential machines.

I know of one constant current machine in which the armature core is forced well up toward the highest saturation obtainable in a dynamo machine. It is able to produce very high electro-motive force, but it does not govern sparklessly by means of a single pair of brushes. Two other types of machine of which I have data work with about 11,000 lines per square centimeter in the armature. In both of these recent changes are along the line of increasing iron and decreasing copper in the armature. I have explicity advised the use of more iron in the armature for two years. One manufacturer recently told me that he is now following my advice with most gratifying results. With the same number of turns on the armature the output is greatly increased. To what extent the iron in the armature can be increased is an open question. It has now been carried beyond a cross-section equal to seventy-five per cent. of the wrought iron in the field cores. If increased cross-section of the core introduces sparking, this can be avoided by increasing the number of bars on the commutator so as to decrease the self-induction in the section under short-circuit by the brush. Indeed, if the output is kept the same, increase of iron decreases turns of wire, and to that extent decreases self-induction. In a machine with two pairs of brushes the effect is to diminish the angular embrace of each pair.

It is interesting to compare two machines of almost exactly the same capacity, but differing widely in relative core section and armature-turns. Let the two machines be represented by A and B. The data of the two are given in the following table:

Machine.	Total Volts.	Revolutions per Minute.	Segments in Commutator.	Turns per Segment.	Total Turns.	Cross-section of Iron. Square Inch	Lines per Square Inch.
A, ...	2,900	1,000	132	36	4,752	265	70,800
B, ...	2,800	875	120	72	8,640	14	79,000

The maximum number of lines of force running through the armature of the A machine is 3,650,000; of the B

machine, 2,213,000. The two machines are designed for the same current of a little under ten ampères. The ratio of the ampère-turns on the armatures of the two is nearly inversely as the cross-section of their iron cores. The ampère-turns on the B armature is eighty-two per cent. greater than on the A armature. It is not probable that the field ampère-turns on B is eighty-two per cent. in excess of those on A. Unfortunately, those particular data are lacking, but the magnetic circuit of A is quite as good as that of B. It does not appear at all probable, therefore, that Professor Ryan's rule applies to both machines.

It is gratifying to our national pride that American designers have successfully carried the Gramme ring constant current dynamo to an output far beyond what some foreign electricians with more theory and less practice in this direction still declare to be impracticable. The writer of a series of articles, now running in the London *Electrical Review*,* says: "beyond about 1,000 volts it is found, in general, to be impracticable to work a closed-coil armature; for either there will be a wasteful lead, or there will be vicious sparking under the brushes, or the current will flash from strip to strip, and will destroy the commutator." * * * "It seems more than probable that machines of that kind will not stand any serious alteration of load if worked at higher voltages, owing to the great range of lead which would be required, and the consequent sparking and flashing over." Again he says: "there is of necessity a large armature reaction in certain forms of arc light machines; and when this is the case, the brushes would require to be shifted right into the centre of the pole arc before sparking would cease, if there were very many turns on each section. The wastefulness of this practice consists in the large number of back-turns and cross-turns which it involves." But in the face of such declarations as these a large number of American machines are now running at an output of 9·6 ampères and from 5,000 to 10,000 volts. A very considerable number of closed-coil

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* *Electrical Review*, August 25, 1893.

Gramme rings giving 5,000 volts are in actual use without breakdown, and without any of the fatal drawbacks predicted by the writer quoted.

The design of closed coil Gramme rings for high potential arc lighting has thus far been limited to the two-pole type of field magnet. This involves the maintenance of higher speed than engineers find desirable. The conditions of present practice and the requirements for the immediate future demand a new departure in this class of dynamo design. All indications point toward a multipolar machine of about fifty kilo-watts capacity and slow speed. The armature will contain a liberal amount of iron, much larger than would be found desirable for constant potential machines. Such a dynamo is already in demand, and it will find an immediate field for the lighting of large cities.

The RESISTANCE of SHIPS.

By Richard Lano Newman.

[*A paper read before the Section of Engineers and Naval Architects, January 24, 1894.*]

No branch of the theory of naval architecture has a richer literature than that which forms the subject of this paper. It would be a formidable task merely to enumerate the names of eminent mathematicians, and experimentalists who have endeavored to discover the laws of the resistance which water offers to the progress of ships, and still more formidable would be any attempt to describe the very various theories that have been devised. Again and again, has the discovery been announced of the "form of least resistance," but none of these have largely influenced the practical work of designing ships, nor can any be regarded as resting on a thoroughly scientific basis. In fact, at the present time it is generally accepted as a fact, that the problem is one that pure theory can never be expected to solve.

Before dealing with what is generally known as the modern theory (*i. e.*, the stream line theory, on which the most successful of our high-speed ships have been built), let us take a brief glance at what a few of the many workers in this field of science have contributed to the solution of the problem during the past 150 years.

Foremost among those who have investigated this difficult problem is Sir Isaac Newton, who, in the second book of his *Principia*, has demonstrated that the resistance opposed to bodies which move in a fluid varies as the square of the velocity of the body; but this has been proved to be applicable only to bodies having comparatively low velocities. It is evident, therefore, that a theory based on such conditions would not be applicable to naval architecture, one of the objects of which is to obtain high velocities.

Following Newton came Daniel Bernoulli. He considered that the resistance should be represented by two terms, one denoting the square of the velocity, the other being a constant; but this was opposed by D'Alembert, who carried on his enquiries in a different manner, and succeeded in representing the theory of fluids in a more general formula than had hitherto been done.

In attempting to apply a theory of resistance to naval architecture, most of the authors of the greatest eminence who wrote on this subject down to the time of the Abbé Bossut followed Newton in supposing the resistance to vary as the square of the velocity; for, up to this time, the theory that affirmed this to be correct had not been shown to be erroneous.

In the year 1775, a series of experiments was made at Paris, under the direction of the Comptroller-General of Finances, with the assistance of the Abbé Bossut, M. D'Alembert and the Marquis de Condorcet. The magnitude of these experiments exceeded anything that had hitherto been attempted in this direction. The experiments were first carried out with the object of testing the then existing theories, and if none of them could be verified, to procure data to serve as a basis for a new solution.

The Abbé Bossut remarked, in his report, that that advice

was the more conclusive, as M. D'Alembert had solved the question by a new and strictly analytical method, which would leave nothing to be wished for, could the equations which are deduced be integrated, either by converging series, or by any other method. But unfortunately this was the point on which they failed. The results of these experiments did not agree with any of the then known theories, as they all previously supposed the resistance to vary as the square of the velocity. Although an investigation of the tabulated results would prove very interesting, it must suffice for our purpose to give a brief summary of the report, as time will not permit a further investigation.

Summary of Report.—The resistances experienced by the same body, whatever may be its figure, moved with different velocities through a fluid infinite in extent, are very nearly in proportion to the squares of the velocities. It has been shown that the resistance varies in a rather greater ratio than that of the square. Experiment, therefore, agrees on this point very nearly with theory. (Here we must remember that the velocities at which the models were propelled were comparatively low, the highest being only 260 feet per minute.)

The resistance which arises from motion in oblique directions do not diminish, everything else remaining the same, in proportion to the square of the sines of the angles of incidence; therefore, on this head, the common theory of the resistance of fluid should be abandoned altogether, when the angles of incidence are small; as then the results deduced from it would be erroneous. It is evident, also, that it cannot be employed to find the solid of least resistance, nor generally to determine any curve, for in such problems the law of the curvature is an unknown element; but for curves in which the angles of incidence are large, as from 50° to 90°, we may make use of the theory; always remembering that the resistance which will result will be rather less than those given by experiment, and that the error will be greater in proportion as the angles of incidence are smaller.

It is also interesting to note that these same investi-

gators touched on the question of resistance as affected by the depth of water, and their experiments proved conclusively that this item was not to be neglected. Of the truth of this law, we have quite recently had an illustration viz: when the cruiser *New York* went on her official run.

The Chevalier du Buat deduced from his experiments a conclusion directly at variance with the common theory, and I only give it, that you may compare it with that now generally accepted. He gave the result of his experiments which present the following ratio: The pressure of a stream on the anterior surface of a stationary body being 1, that on a body moving through a still fluid is only 0·843. Whatever may have been the cause of the difference he observed, the result showed that the subject requires further investigation by practical means.

A paper on this subject, in the *Encyclopædia Britannica*, contains the suggestion of the existence of a quantity of stagnant fluid at the anterior and posterior parts of the body; but Du Buat arrived at the conclusion that the water at the head of a vessel is not perfectly stagnant; but that it recedes in filaments, from the axis, in curves which converge to the surface of the vessel, and ultimately escapes with an accelerated velocities round its sides.

The same author continues that if it were fully established that there is a quantity of water stagnant, or nearly stagnant, the next step to be considered would be that form of the extremities which would reduce this quantity of stagnant water to a minimum.

Now, at first sight this seems a peculiar theory, but, if carefully looked into, it will be found to compare favorably with our present views, especially in respect of the latter portion.

The same investigator also proved that by adding to a cubical body so as to make its length three times its breadth, its resistance was considerably reduced, showing, as you see, that in these early days it was recognized that the length of a ship was a factor to be considered in relation to the question of her speed.

Another worker in this field was Don George Juan, a

Spanish nobleman of high rank in the naval service of his country, and a member of most of the principle scientific bodies in Europe. To attempt an explanation of his theory would be rather beyond the scope of this paper, and would, I am afraid, prove of little service to us, as he bases his theory on the assumption that the resistance will vary as the hydrostatic head; but those who desire to examine his views will find them set forth in the first volume of Creuze's *Naval Architecture.*

Between the years 1796 and 1798, some very exhaustive experiments were made by the Society for the Improvement of Naval Architecture, at the Greenland Dock, London, England. They showed that the power of the velocity of the bodies used in the experiments of the year 1798, at two miles per hour, was, in general, a little above the square, but that the ratio gradually decreases as the velocity increases, and becomes a little less than the square at the velocity of eight miles per hour. And, with respect to the bodies used in the year 1796, it also appears that the power of the velocity, with the said bodies, is considerably less than that of the bodies used in 1798, and is always less than the square. This difference in the power of the velocity of 1798 and 1796, arises from the bodies used in 1796 having a much greater surface exposed to frictional resistance than the bodies used in 1798, and also because the said friction always increases in a much smaller ratio than the square. So that the friction of the bodies used in 1796 forms a greater proportional part of their total resistance than it does in the bodies used in 1798.

Colonel Beaufoy, who was engaged on the foregoing experiments, at a later date continued his investigations to test the correctness of the formulæ:

Oblique resistance = direct resistance $\times$ sine $^2\theta$, and he succeeded in proving the assumption to be incorrect, but we will revert to this subject later on.

In the year 1806, Admiral F. H. Chapman, of the Swedish Royal Navy (who had previously developed a theory of resistance which in itself is rather a curiosity), gave to the world the labors of the later years of his life, in which he

advocates the parabolic system of constructing ships. What he did was to base his reasonings on the results of ships which had been found to possess good qualities, and then subjecting the same to scientific investigation. He began by endeavoring to discover whether the reduction of the areas of the transverse sections in well-constructed ships followed any law. For this purpose he calculated the areas of the sections of several ships; and in order to make the numbers more convenient, he divided the areas by the breadth of the midship section; then setting off from the water-line, at the respective stations on the drawing, distances equal to the quotients, he traced a curve representing the areas, which he called a curve of sections. He then endeavored to find the equation to the curve, or rather, that of another curve which would coincide with this for the greatest length; he found that if the power and parameter of a parabola were so determined as to allow that curve to pass through three given points of the curve of sections, the two curves would nearly coincide. Chapman consequently concluded that if the areas of the several sections of a ship were made to follow the law of the abscissæ of a parabola, a vessel of good qualities might be formed. This, as you see, is opposed to the theory of M. Romme, who inferred, from his experiments, that it made no difference whether the water was divided by a curved surface or by a plane surface, being the chord of such curve.

Now, gentlemen, having taken a rough survey of what some of the most eminent workers in this field have done, we will come down to the early sixties, and see what progress had taken place up to that time.

In the year 1863, a naval architect, in advocating the probability of crossing the Atlantic in one-half the time then occupied, made the following remark, which in itself seems to me to be more or less of an apology for the rashness of his statement: "our present necessities demand a class of vessels that will reduce the voyage between Europe and America to an average of one-half the time, and at a cheaper rate. I have endeavored to indicate how, I think,

this may be accomplished, and trust that my ideas may be regarded by the enterprising merchants of this country, if not by the admiralty, as worthy of consideration. If the thousands of intellects at work on this problem did not believe that it was susceptible of a solution, it would indicate a species of wide-spread monomania. I simply believe that the prevailing sentiment and conviction foreshadows the event."

At the present time we know that the event is not only possible but an accomplished fact, and the several causes that have enabled us to accomplish it may be enumerated as follows:

(1) Improved methods and materials used in construction.

(2) Recent researches to establish the form of least resistance, turning principally on the modern theory of resistance.

(3) Improvements in the machinery used for propulsion, etc.

In the year 1862, a number of experiments were made with H. B. M. SS. *Warrior* and *Black Prince*. As these ships were built from the same drawings, and the engines were built by the same firm from one set of patterns, it might reasonably have been supposed, under these circumstances, that the two ships would have been as nearly as possible equal in speed; but the results proved the *Black Prince* to be the slower boat by at least one knot. The reasons assigned to account for this at the time were many and unreliable. One expert stated the cause as follows: On trial the *Black Prince* drew eight and one-half inches more water than her sister ship, consequently her resistance would be greatly augmented. He says: "in the aggregate, I estimate the law of resistance to be according to arithmetical progression. That is, if the resistance to a solid body, moving at a given velocity, be represented by 1 at the first foot from the surface, it will be 2 at the second, 3 at the third, and so on." This is entirely opposed to our modern theory, and to which I particularly wish to draw your attention, as I have no doubt some of my hearers hold views on this subject similar to those which I at

one time did, and which upon investigation I found to be erroneous.

Mr. Scott Russell, who was a great authority on all subjects connected with ship-building, used to compute the probable resistance of a ship in the following manner. He had ascertained that at ten knots per hour, with a vessel of what he termed the proper form (?) of 1,500 tons burden, the head resistance could be reduced to fifty pounds per square foot. He had also ascertained how much a similar vessel could be propelled with, by engine power alone, including the loss due to the working of the engines, and he found that whilst the direct resistance to a ship going ten knots per hour was only fifty pounds per square foot of midship section, including all loss from communication by paddle wheels, air pumps and other sources, except the slip, this resistance was not more than sixty-five pounds per square foot of midship section. Thus he could calculate confidently to a quarter of a knot, as he had done for many years with his peculiar shape of ship, the amount of power necessary to propel a given ship at a given speed; for instance, where a speed of ten knots was desired he provided fifty pounds per square foot of midship section, for the resistance of that ship; and when he had to overcome the resistance of the machinery also, he made this up to sixty-five pounds per square foot.

This in all probability was a very good rough-and-ready rule for the then comparatively low speeds run, but, as you see, it only involves the midship section, and had he used this rule for higher velocities, he would have found that there were other conditions to be considered.

The Stream Line Theory.—Many eminent English mathematicians have been concerned in the introduction and development of this theory, but chief among them are the late Professor Rankine and the late Mr. W. Froude. The former practically applied the theory to calculations (see his treatise on *Ship-building, Theoretical and Practical*), and the latter for years conducted experiments for the British Admiralty, beyond all comparison in value with any that have gone before them. Since his death, his son has continued the

experiments on the lines laid down by the father, the results of which may be judged by the number of high-speed ships now traversing the ocean.

Water, as you know, is not a perfect fluid; that is to say, its particles do not move past one another with perfect freedom, but exercises a certain amount of rubbing or *friction* upon one another, and upon any body past which they move. Suppose a thin board with a plane surface to be moved through water. It will experience what is known as *frictional resistance*. The amount of this resistance will depend upon the area and the length of the plane, as well as its degree of roughness and the rate of its motion. If this same plane be moved in a direction at right angles to its surface, it experiences what is termed *direct* or *head* resistance, the amount of which depends on the area of the plane and the rate of its motion. Should the plane be moved obliquely it experiences a resistance which may be regarded as a resultant of *frictional* and *direct* resistance.

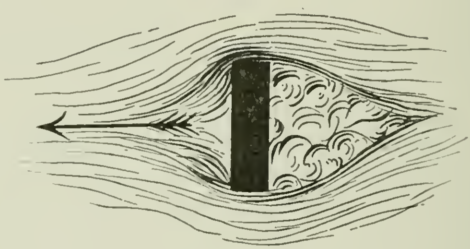


FIG. 1.

Suppose either of those resistances to take place, the plane would leave an eddying *wake* behind it, as indicated by *Fig. 1*, and this disturbance among the particles of water is a very important element to the resistance of the body. If the plane is not wholly immersed, or its upper edge is near the surface, it will heap up water in the front as it advances, and create waves which will pass off into the surrounding water, to be succeeded by others. Such wave-making requires the expenditure of power, and constitutes a virtual increase in the resistance. If the plane were wholly immersed, it would create little or no surface disturbance,

and, consequently, the body would require less force to propel it at a given speed. If there were no surface disturbance, the resistance would remain constant, irrespective of the depth of immersion. This statement is directly opposed to the opinion, frequently entertained, which confuses the greater hydrostatical pressure on the plane, due to its deeper immersion, with the dynamical conditions incidental to motion. It may, therefore, be desirable to add a brief explanation.

Suppose a plane to be deeply immersed; it is evident that the forces on its back and front balance one another at any depth. Now suppose the plane to be in motion, at each instant it has to impart a certain amount of motion to the water disturbed by its passage, but the momentum thus produced is not influenced by the hydrostatic pressure on the plane corresponding to its immersion. Water being practically incompressible, the weight of water set in motion will be constant at any assigned speed, and consequently the resistance, neglecting of course any surface disturbance. For instance, Colonel Beaufoy proved by experiment that the resistance of a plane moving normally to itself, at depths of three, six and nine feet below the surface, were practically identical. The following rule was also established as the result of these experiments. The resistance per square foot of area, sustained by a wholly submerged plane moving normally to itself through sea-water at a uniform speed of ten feet per second (which is very near six knots per hour), is 112 pounds; and for other speeds, the resistances vary as the square of the speed.

As before stated, Colonel Beaufoy also showed that the oblique resistance was not equal to the direct resistance $\times$ *sin*^{2} of the angle of incidence. Table II contains a sum mary of his results.

Angle of Plane with Line of Motion.	90°	80°	70°	60°	50°	40°	30°	20°	10°
Sines of angles, . .	1·	·985	·940	·866	·766	·643	·5	·342	·174
(Sines)^2 of angles, .	1·	·97	·88	·75	·587	·413	·25	·177	·03
Resistances, ...	1·00	·915	·845	·828	·722	·579	—	·321	·272

From this table it appears that up to angles of 50° to 60°, the resistance varies with a fair approach to agreement, but for angles from 50° down there is a considerable difference.

The theoretically correct law has been determined by Lord Rayleigh, and is as follows:

Let P = the direct resistance, and P' the corresponding resistance due to the inclination of the surface.

Then

$$P' = \frac{2\,\pi\,\sin a}{4 + \pi\,\sin a} \times P = \frac{\sin a}{\cdot 637 + \cdot 5\,\sin a} \times P$$

In Table II the results of this formula is shown:

Angle of Plane with Line of Motion.	*90°*	*80°*	*70°*	*60°*	*50°*	*40°*	*30°*	*20°*	*10°*
Sines of angles, . .	1·	·985	·940	·866	·766	·643	·5	·342	·174
P', ...	—	·872	·849	·809	·7509	·6708	·56	·423	·2403
Resistances, ...	1·00	·915	·845	·828	·722	·579	—	·321	·272

This formula takes no account of the negative pressure on the back surface of the plane.

M. Joëssel, of the French Navy, has conducted a series of valuable experiments on the same subject, and has deduced therefrom a formula similar in form but not identical with Lord Rayleigh's. It is as follows:

$$P' = \frac{\sin a}{\cdot 39 + \cdot 61\,\sin a} \times P$$

In Table III the result of this formula is shown:

Angle of Plane with Line of Motion.	*90°*	*80°*	*70°*	*60°*	*50°*	*40°*	*30°*	*20°*	*10°*
Sines of angles, .	1·	·955	·940	·866	·766	·643	·5	·342	·174
P', ...	—	—	—	—	—	—	—	—	—
Resistances, ...	1·	·915	·845	·828	·722	·579	—	·321	·272

Frictional resistance is measured by the momentum imparted to the water in a unit of time; this momentum being imparted, at each instance, to a current or *skin* of

water, which is adjacent to the surface. The extent to which the frictional resistance causes disturbance—that is to say, the "thickness of the skin"—varies with the velocity and other circumstances of the motion. From instant to instant the frictional current thus created is left behind in the form of a "frictional wake," which follows the surface. The governing conditions of the frictional resistance are the area and length of the plane, its degree of roughness and the speed of advance.

The following are a few of the experiments of the late Mr. Froude, as summarized by himself.

Nature of Surface.	Length of Surface or Distances from Cut-water, in Feet.											
	2 feet.			8 feet.			20 feet.			50 feet.		
	A	B	C	A	B	C	A	B	C	A	B	C
Varnish, ...	2·09	·41	·390	1·85	·325	·264	1·85	·278	·240	1·83	·250	·226
Paraffine, ...	1·95	·38	·370	1·94	·314	·260	1·93	·271	·237	—	—	—
Tinfoil, ...	2·16	·30	·295	1·99	·278	·263	1·90	·262	·244	1·83	·246	·232
Calico, ...	1·93	·87	·725	1·92	·626	·504	1·89	·531	·447	1·87	·474	·423
Fine sand, ...	2·00	·81	·690	2·00	·583	·450	2·00	·480	·384	2·06	·405	·337
Medium sand, . .	2·00	·90	·730	2·00	·625	·488	2·00	·534	·465	2·00	·488	·456
Coarse sand, . . .	2·00	1·10	·880	2·00	·714	·520	2·00	·588	·490	—	—	—

He says: "This table represents the resistances per square foot due to various lengths of surface, of various qualities, when moving with a standard speed of 600 feet per minute, accompanied by figures denoting the power of the speed to which the resistances, if calculated for other speeds, must be taken as approximately proportional.

"Under the figure denoting the length of surface in each case are three columns, *A*, *B*, *C*, which are referenced as follows:

"*A*. Power of speed to which resistance is approximately proportional.

"*B*. Resistance in pounds per square foot of surface, the length of which is that specified in the heading, taken as the mean resistance for the whole lengths.

"*C.* Resistance per square foot on unit of surface, at the distance sternward from the cut-water specified in the heading."

From these experiments the following deductions have been made:

(1) That the law formerly assumed to hold is very nearly conformed to, the frictional resistance varying approximately as the square of the velocity, when the area, length and condition of the surface remains unchanged.

(2) That the length of the surface sensibly affects the mean resistance per square foot of wetted surface; especially so when very short lengths are compared with planes of fifty feet and upward. For greater lengths than fifty feet it appears that the mean resistance per square foot of area remains nearly constant. Mr. Froude explains this important experimental fact as follows: The portion of surface that goes first in the line of motion, in experiencing resistance from the water, must in turn communicate motion to the water in the direction in which it is itself travelling; consequently, that portion of the surface which succeeds the first will be rubbing, not against stationary water, but against water partially moving in its own direction, and cannot, therefore, experience as much resistance from it.

A third important deduction is the great increase in frictional resistance due to a very slight difference in the apparent roughness of the surface. For instance, the frictional resistance of a surface of unbleached calico was shown to be about double that of a varnish surface, and a varnished surface gave results about equal to that of a surface coated with smooth paint, tallow, or composition such as is generally used on the bottoms of ships. The frictional resistance of such a surface, moving at a speed of 600 feet per minute, would be about one-fourth pound per square foot, which would give a frictional resistance of about one pound per square foot of immersed surface for the clean bottoms of iron ships when moving at a speed of about 12·8 knots. This unit is worth noting.

The foregoing will assist us in following the reasoning

of the more difficult problems connected with the resistance of ship-shaped solid bodies, as it is now generally acknowledged that satisfactory experiments on the resistance of ships can only be made with ship-shaped models of reasonable dimensions.

In the modern theory, the total resistance is considered to be made up of three principal parts:

(1) Frictional resistance due to the gliding of particles over the rough bottom of the ship.

(2) "Eddy-making" resistance at the stern.

(3) Surface disturbance, or wave-making resistance.

The second of these divisions only acquire importance in exceptional cases; it is known to be very small in well-formed ships. We will, therefore, bestow most attention upon frictional and wave-making resistance, examine the conditions governing each, and contrast their relative importance. In considering this subject we will assume the ship is either dragged or driven at a uniform speed by some external force which does not affect the flow of water relatively to her sides. The reason for this is to enable us to consider those resistances which are affected by the ship's form, the condition of her bottom, etc., whereas there are other conditions to be considered when treating of propulsion and which I hope to touch on before finishing this paper, as the compilation of these notes was first intended for my own information only, and to enable me, if possible, to obtain a clearer insight into those several elements that constitute the total resistance of a ship.

Suppose the ship to be moving ahead at a given velocity through an ocean unlimited in extent, and motionless relatively to the ship other than the disturbance caused by her passage. Now this would be equivalent, and the condition would remain unchanged if we assume the ship to remain stationary and the ocean to move past it in a direction opposite, and at a velocity equal, to that of the ship. This latter supposition enables us to trace more simply the character of the disturbance caused by the introduction of a hull of a ship at a certain speed into water that was previously undisturbed. Let us also assume the water to be

absolutely frictionless, and the bottom of the ship perfectly smooth. This is of course a hypothetical condition, and is only introduced to enable us at a later stage of the enquiry to arrive at what are the actual conditions.

In *Fig. 2*, let the black body in the centre represent the water-line plan of a ship, and the lines the paths traversed by the water in passing it. If we imagine for a moment the ship to be lifted out of the water, the path traversed by any set of particles would be represented by a straight line running parallel to the centre line of the ship. Now, if we immerse the ship, as indicated by *Fig. 2*, any set of particles in a given stream line will still continue to approach the ship in a direction parallel to her keel until such times as it reaches that sphere influenced by her presence, when their path will be diverted laterally, as indicated by the stream lines. How far in front of a ship her influence would be

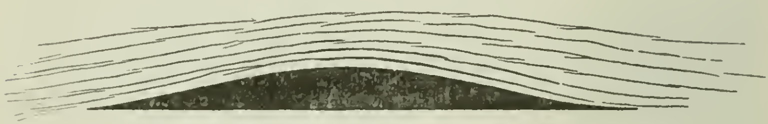


FIG. 2.

felt would, I think, be difficult to conjecture; but there would no doubt be a limit, both in front and at her sides, at which points the water would still continue to move in its original direction. If the foregoing is correct, it follows that with this lateral diversion, and limit to the sphere of influence at the sides, the velocity of flow at the midship section must be accelerated. This acceleration should be gradual, but will depend on three causes:

(1) The velocity of flow.

(2) The bow of the ship.

(3) The breadth of the ship, or the amount of this lateral deflection.

At the broadest part of the ship the velocity of the particles will be the greatest, owing to the fact of the stream line being at its narrowest, and the same quantity of water having to pass as at the foremost area. After the midship

section has been passed the particles should converge gradually toward the keel line, and their speed will again receive a check. Finally, after flowing past the ship, and attaining such a distance astern as to place them beyond the influence of the ship they again attain their original direction and flow, providing there is no surface disturbance. This last-named condition would only be possible in a ship wholly submerged at a great depth below the surface of an ocean limitless in extent. But in actual ships partly immersed, the retardation and acceleration referred to must cause the formation of a bow and stern wave.

[*To be concluded.*]

BOOKS RECEIVED.

[In sending books for notice in the *Journal*, publishers are requested, for the information of the reader, as well as for their own advantage, to give the price. This announcement by title will be followed, in most cases, by a review, which will appear at the earliest opportunity.]

Commonwealth of Pennsylvania. Report of Commission Appointed to Investigate the Waste of Coal Mining, with the View to the Utilizing of the Waste. Philadelphia: Allen, Lane & Scott. 1893. 8vo.

Knudsen, A. Triangular Surveys from Single Stations. San Francisco: Brunt & Co. 1893. 18mo.

Van Nostrand Science Series. No. 101. The Sextant and other Reflecting Mathematical Instruments. New York: D. Van Nostrand Company. 1891. 18mo. Price, 50 cents.

Do. No. 105. Determinants, an Introduction to the Study of, with Examples and Applications. New York: D. Van Nostrand Company. 1892. 18mo. Price, 50 cents.

Do. No. 109. The Measurement of Electric Currents. Electrical Measuring Instruments. Meters for Electrical Energy. New York: D. Van Nostrand Company. 1893. 18mo. Price, 50 cents.

Vick's Floral Guide for 1894. Rochester: James Vick's Sons. n. d. 8vo. pph. Price, 10 cents.

American Humane Education Society. Autobiographical Sketches and Personal Recollections of George T. Angell. Boston: Society. n. d. 8vo. pph. Price, 10 cents.

The Strike at Shane's. Gold Mine Series No. 2. Sequel to "Black Beauty." Boston: Society. n. d. 12mo. pph. Price, 10 cents.

BOOK NOTICES.

A Text-book on Electro-magnetism and the Construction of Dynamos. Vol. I. Electro-magnetism and the construction of continuous current dynamos. By Dugald C. Jackson, B.S., C.E. New York and London: Macmillan & Co. 1893. 8vo 281 pp. 132 illustrations. Cloth.

Among the many books on dynamos that have appeared within the last few years, this recent addition, the first volume of which has just appeared, must undoubtedly be classed as one of the best. It is written in a logical, clear and yet concise form, and treats of the fundamental principles and their application in a sufficiently complete manner, without resorting to voluminous padding, old cuts and unnecessary and historical details. The theory of the dynamo is treated from a strictly modern standpoint, and is based upon the latest researches and the best American practice. The treatment is necessarily mathematical, but only so far as is absolutely necessary, all elaborations being omitted, and the reader finds theory and practice combined in a very satisfactory way. The introduction of the calculus and the omission of elementary physics and mechanics and the addition of copious references are all welcome features, as the book is designed as a text-book for college students and others who have had an equal preparation.

The work is divided into two volumes: the first treating of electro-magnetism in general and direct-current dynamos in particular, and the second (to appear soon) of series arc lighting and alternating current machinery.

The first chapter takes up the primary definitions and evaluations and explains very clearly the qualitative and quantitative relations existing in the magnetic circuit. Chapter II includes a brief description of typical electro-magnets and their design for specific work. Chapter III is a discussion of the magnetic properties of iron and includes various methods of experimentally determining permeability and hysteresis, the effect of the physical properties and chemical composition of the iron and the loss of energy in hysteresis, all of which is illustrated by means of useful curves. Chapters IV and V treat respectively of the establishment of electrical pressures and of the magnetic circuit of the dynamo, and include the theory and design of armatures and field magnets. The fundamental principles are developed clearly, the various losses and allowances made in modern practice are given and also several examples of calculations. Chapter VI is devoted to the compensation for cross-turns and the effect of brush contact—an important subject which has hitherto received but little attention in books. Chapter VII is on characteristic curves, the regulation of dynamos and their connection for combined output. The four characteristic curves are described and their determination and interpretation explained. The principles underlying the various methods of regulation and the application of the same, and also the methods of connecting dynamos for parallel working,

are all given in a very satisfactory manner. A chapter, ably discussing the subject of efficiencies and one on multipolar generators concludes the book.

The cuts are new and well made, the typography excellent and the general get-up of the volume displays unusual good taste.

The book is not intended for, nor will it be of much use to, so-called "beginners" and "practical men" and others having little knowledge of physics and mathematics, but to advanced students and those desiring to study the subject of the theory and design of dynamos, it cannot be too highly recommended. H. S. Hg.

Alternating Currents. An analytical and graphical treatment for students and engineers. By Frederick Bedell, Ph.D., and Albert Cushing Crehore, Ph.D. Second edition. New York: The W. J. Johnston Company, Limited, 41 Park Row. London: Whittaker & Co., Paternoster Square. 1893. 8vo. 325 pp. 112 illustrations. Price, $3.

The first edition, which appeared about a year ago, was exhausted in a few months, and the second edition has already appeared. The popularity of the book has been further evidenced by the fact of its translation into the French and German.

For the benefit of those who are not acquainted with this book, it might be well to add that it contains an analytical and graphical treatment of the subject of alternating currents in simple and divided circuits containing resistance, self-induction and capacity, with a view to enabling problems to be solved which involve these quantities.

The discussions are very clear and exact, and can readily be followed by advanced students. The work is divided into two parts: the first containing the analytical, and the second the graphical, treatment. After an introductory chapter on primary definitions and one on harmonic functions, the various combinations of resistance and self-induction, resistance and capacity, and self-induction and capacity are taken up, including oscillating and non-oscillating charges and discharges, etc.

Numerous problems are worked out, and altogether the subject is handled in a logical manner and is well arranged for study, and though of little practical importance, it is nevertheless very useful to students. H. S. Hg.

Transformers. By Caryl D. Haskins. Lynn, Mass.: Bubier Publishing Company, 5 x 7. Cloth. 150 pages. Illustrated.

This book is written specially for use of the central station engineer and the student, and claims to be a semi-technical, yet semi-popular treatise.

The attempt is made to present the subject in a clear and simple style, with scarcely any mathematics, but much of the matter is vague and contains too much of a mixture of simple phrases and complex terms, and the reader misses a logical presentation of the fundamental principles.

Following the introductory matter on induction, comes a demonstration of why alternate currents afford the only "economic means for the distribution of light," and a brief explanation of some of the methods of distribution. Such ambiguous and even incorrect terms as the "creation" of a cur-

rent; "an electric current comes into existence;" "'electrical induction' is that force which 'persuades,' 'actuates' or 'impels' an electrical current in one body by the influence of current in another;" "units of force pushing against" units of force, in speaking of the action of counter electro-motive force; electro motive force is "the number of volts pressure present at any given point in a circuit," etc., are apt to confuse the reader and give him a very wrong conception of the subject.

In the second chapter, on "theoretic considerations," the questions of self and mutual induction, regulation, electro-magnetism, "magnetic currents," eddy currents, hysteresis, etc., are briefly considered, but it would be difficult for one who is unfamiliar with the subject to understand much about it, from the author's exposition, as many important steps are omitted and fundamental principles only vaguely explained.

It would have been better had the third chapter on "The Theory of the Transformer Mathematically Considered" been omitted, as it is useless to the class of readers for whom the book is designed. It gives a list of symbols to be used in the discussion, and then uses others in the formulæ without explaining what they are. Also, the author says, "a knowledge of algebra only is presumed," yet the equations contain differentials, and little or no explanation is given either of the meaning or the deduction of the expressions, so that only to one familiar with the subject are they intelligible. Symbols are used that are not defined, which makes it still more difficult to follow the argument. There is little in the chapter, except the two pages from S. P. Thompson's *Dynamo-Electric Machinery* which, although intended for advanced students, has been used bodily, with but little change in the text and no adaptation of the treatment to meet the requirements of an elementary book.

The concluding chapters, on the "Evolution of the Transformer," "Transformer Construction," "The Transformer in Service" and "Commercial Transformers" are much better than the preceding ones, and the author is evidently more at home in the description of commercial apparatus and in dealing with practical considerations. These chapters may be read with profit, and go far to atone for the shortcomings of the others.

Several appendices and a short (but unsatisfactory and misleading) glossary of terms, close the book. H. S. H.

King's Hand-Book of New York City. An Outline History and Description of the American Metropolis. With over 1,000 illustrations from photographs made expressly for this work. Edited and published by Moses King, Boston, Mass. 1893. Second edition. Price, $2.

This work is one of the best of its kind that we have ever seen—so much in advance of the average guide-book that comparison is out of the question. It is introduced by an extremely interesting historical sketch of the city from its foundation, through the various prominent periods of its growth, to the present; and then proceeds to take up in order the various features and institutions of the city, giving in condensed form a surprising amount of information on every topic of local interest, including practically everything the

visitor would be likely to seek to know, and much that the native will find of value to have in convenient form for ready reference. It is, in brief, a carefully prepared digest of information concerning the history, municipal government, commerce, trade, manufactures, financial, educational, benevolent institutions, public and other prominent buildings, parks, places of local or historical interest, etc., presented in a form unusually complete for a work of its class. The profusion and general excellence of the illustrations, all of which are new, add greatly to the utility and attractiveness of the work.

W.

The Measurements of Electrical Currents and other Advance Primers of Electricity. By Edwin J. Houston, A.M. New York: The W. J. Johnston Company, Limited, 41 Park Row. 429 pages. 169 illustrations. Price, $1.

Electrical measurements and other advanced primers of electricity forms the second volume of Professor Houston's series of elementary electrical treatises, for students and non-technical readers. A third volume will complete the series, but there is no necessary connection between the several volumes, each being complete in itself, as likewise are the several primers in each volume, so far as the subjects will permit.

The book derives its title from the first three primers, which relate to the measurements of electric currents, electro-motive forces and resistances, respectively. The object of these primers is not so much to teach the practical operations of electrical measurements as to explain in simple, but exact terms, the principles upon which they are based and to describe the apparatus used.

Two primers treat of voltaic and thermo-electrical cells and other sources of electricity. The principles of commercial measurements are explained in three primers, and nine others are devoted to dynamos, motors and transformers; the eighteenth and last primer being a review of primer or primers.

The 200 and odd pages on electric lighting and power deal very thoroughly with the different methods and apparatus in practical use. This section will be particularly useful to the large class who wish to obtain a correct knowledge of the applications of electricity. The author's lucid and accurate exposition of general principles will be appreciated by advanced students and practical electrical operatives.

W.

Universal Bimetallism and an International Monetary Clearing House, together with a Record of the World's Money, Statistics of Gold and Silver, etc. By Richard P. Rothwell. New York: The Scientific Publishing Company. 1893. Pp. 53. Price, 75 cents.

The author of this treatise, the editor of the leading mining journal of the United States believes that the time has come when the silver problem should be permanently solved by international agreement providing for universal bimetallism. The specific plan which he proposes for acceptance is ably elucidated and advocated in the pamphlet, and has received high praise from many experts, who have given the subject the most careful consideration.

W.

How to Make Inventions, or Inventing as a Science and an Art. A practical guide for inventors. By Edward P. Thompson, M.E. (Illustrated by Wm. A. Courtland.) Second edition, revised and enlarged. New York: D. Van Nostrand Company. n. d.

The scope of this work is original and purports to be highly practical. Whether it shall prove possible, as the author anticipates, to induce in would-be inventors correct habits of thought and reasoning in the development of their ideas may well be doubted. That, in the case of those already prepared by previous education and training in the rudiments of the scientific method, it will prove an interesting and suggestive book we have no doubt. In such cases, the seed will fall on good ground, and will bear good fruit. The vast majority of so-called inventors, whose fees go to swell the coffers of the Patent Office, and whose creations are brought to light only to be buried beyond hope of resurrection in the massive tomes which issue monthly from its portals, will go on grinding out useless inventions in the old hap-hazard way.

The author's ideas, as advanced in the book, are admirable and worthy of praise, but the trouble about utilizing them lies here. Those who are capable of appreciating and applying his analytical methods, belong to the class that have no need for the book; while of those whom it could benefit, the great majority are persons of untrained and unbalanced minds, who either could not think logically if they would, or would not if they could.

This, however, does not detract from the merit of Mr. Thompson's book, the plan of which is excellently conceived and well carried out. W.

The Ore Deposits of the United States. By J. F. Kemp, A.B., E.M. 4to, pp. 302. Cloth. Numerous illustrations. New York: The Scientific Publishing Company, 27 Park Place. 1893. Price, $4.

The material for this volume was originally collected for service in connection with lectures and instruction given by the author during the past seven years, first at Cornell University and later at Columbia College.

Outside of the transactions of our technical societies, there was, until the appearance of Professor Kemp's book, no source of information accessible to the student and investigator of this important subject. Whitney's *Metallic Wealth of the United States*, published in 1854, an excellent review of our ore deposits in its day, has long since become antiquated, and the few general treatises on the subject are those of foreign authors, in which, while general principles are admirably presented and discussed, there is no information of a descriptive nature relating to American occurrences that are of value to American students. The truth of this statement will become more apparent when it is considered that many of the most important sources of ores in the United States have only been developed within the past decade. Aside from all this, however, it will be admitted that a work of this comprehensive character can only properly be undertaken by one who, like the author, has had the opportunity of making personal observation and study of the formations and locations, and who is thoroughly conversant with the literature of

the subject and able to give to the views and opinions of authorities, often conflicting, their due and proper weight.

There is no one in the United States better qualified than Professor Kemp in respect of professional attainments and practical acquaintance with the subject, to treat it satisfactorily, and he has made a book which will be welcomed by all who are interested in the ore deposits of the United States, as a trustworthy guide. W.

A Manual of Practical Assaying. By H. Van F. Furman, E.M. Third edition. New York: John Wiley & Sons. 1893. Price, $3.

This volume appears to be exceedingly well planned, and should be found a satisfactory guide book for the practical assayer and chemist engaged in commercial analytical work. The chapters on rapid methods of gas and water analysis should prove of much service, as commercial work of this nature is becoming important. The writing of chemical equations and stoichiometry are subjects which are not usually treated of in works of this class with the elaboration which the author gives them, and should add to the usefulness of the work.

Somewhat more attention, in our judgment, might have been usefully devoted to the electrolytic methods, which the labors of Classen, Smith and others have made familiar to students.

The tables at the close of the volume are numerous and particularly useful.

As a whole the work is a very satisfactory one, and will doubtless find a large demand. W.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, February 21, 1894.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 21, 1894.

JOSEPH M. WILSON, President, in the chair.

Present, seventy-four members and eight visitors.

Additions to membership since last report, seventy-six.

Prof. Wm. Libbey, Jr., of Princeton, N. J., who was present by invitation, gave an interesting account of the physical geography of the Hawaiian Islands, illustrating his remarks with lantern views. The meeting passed a vote of thanks to the speaker for his extremely instructive and entertaining address.

Mr. Joseph Richards exhibited and described a specific gravity balance which he had devised for the purpose of automatically registering the percentage of tin in solders. The beam of this balance is accurately graduated

by experimental observation of the record made by a series of carefully prepared alloys of tin and lead. An equal volume of the samples of each composition obtained by casting in a mould, being used for the purpose of standardizing the scale beam. The mode of using the balance consists simply in melting a sample of the solder to be valued, casting the test piece in the mould provided for the purpose, introducing this in a cup made to receive it on the short arm of the lever, and shifting a movable weight along the long arm of the balance until equilibrium is established. The percentage of tin in the sample is then read off directly on the beam. The apparatus is found very convenient by purchasers of solders and especially by purchasers of old solders recovered from waste.

The Secretary gave some account of the work of the Niagara Falls Power Company.

Mr. Samuel Sartain offered the following substitute for paragraph 1 of the special rules for the award of the Elliott Cresson Medal passed by the Institute at its stated meeting of September 20, 1893, to-wit:

(1) "Upon the adoption, by the Committee on Science and the Arts, of a report setting forth that a discovery, invention, improvement or manufacture is worthy of an award of the Elliott Cresson Medal, publication shall be made three times in the *Journal of the Franklin Institute*, stating that at the expiration of three months from the date of the first publication, the applicant will be entitled to receive the award of the said medal, unless within that time satisfactory evidence shall have been submitted to the Committee on Science and the Arts of the want of originality or merit, of the supposed discovery, invention, improvement or manufacture."

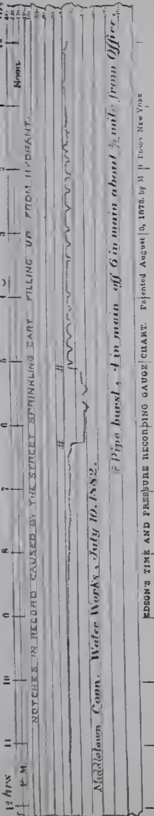
The mover explained that the changes made in the substitute were merely verbal, and were proposed with the view of bringing the phraseology of the rule into literal conformity with the wording of the deed of trust.

The substitute was carried without a dissenting vote.

Adjourned. WM. H. WAHL, *Secretary*.

SPECIMEN RECORD CHARTS—EDSON RECORDING GAUGE.

PLATE No. 1.



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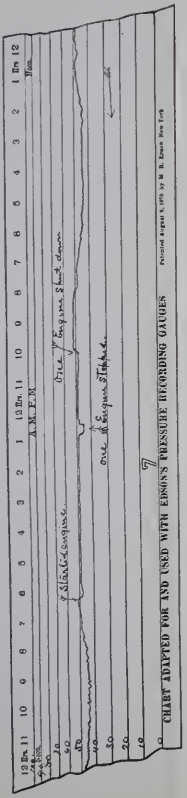

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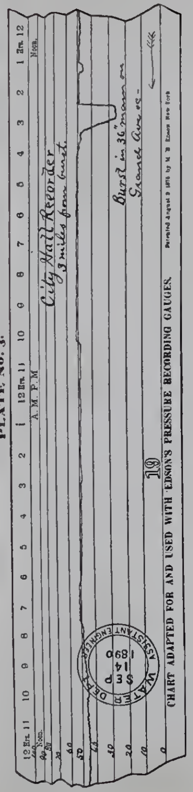

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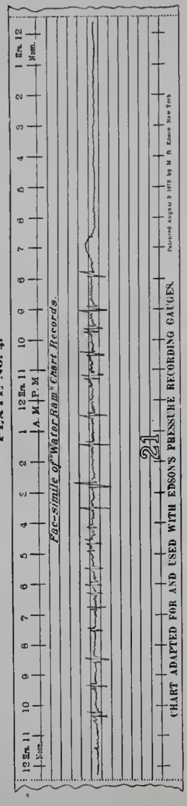

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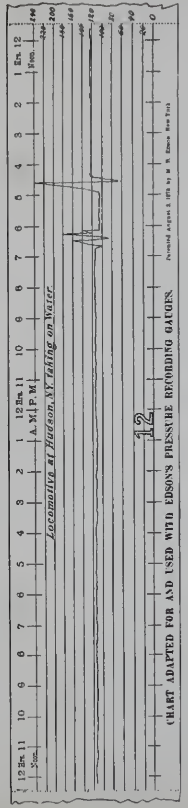

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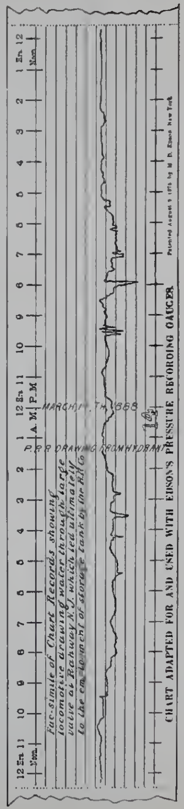

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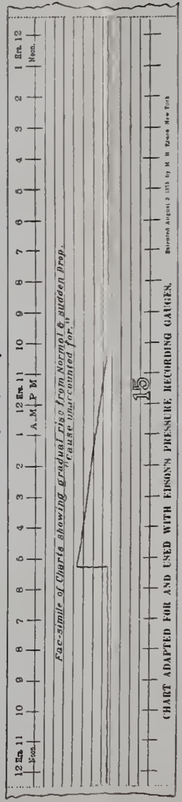

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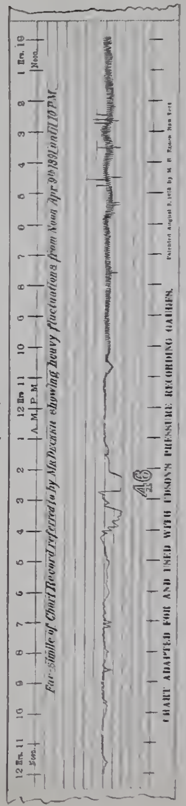

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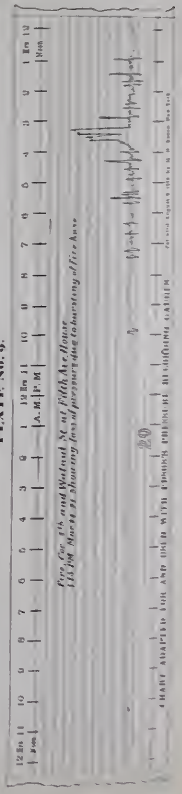

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PRECIPITATION DURING FEBRUARY, 1894.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin.																																
Blooming Grove,	'20									'80‡			'50			'80			'10			'06				1'00						3'40
Browers Lock,		'03		'12					'71	'04		'36	'22		'04			'48		'27		'13				1'08						4'11
Coatesville,				'22					'70	'06		'50	'15		'70			'61	'03	'20					'30	1'00						4'60
Coopersburg,	'02			'09					'64	'03		'44	'21		'50			'58		'43		'11			'06	1'26						4'26
Doylestown,		'02		'05					'60			'41	'26		'63			'51	'19						'07	1'37						4'28
Dyberry,	'10			'02					'48	'07		'56	'18		'54	'05		'11		'02						'60						2'73
Easton,	'05			'14						'77				'52	'42	'01		'35		'03		'11				'50						3'39
Forks of Neshaminy,	'02			'10					'69	'05			'55		'54			'50		'21						1'02						3'77
Frederick,				'90					'51	'03		'21	'15		'55			'42	'20		'03				'05	1'05						4'11
Hamburg,	'07			'12					'79			'41		'47				'27		1'04						1'20						4'47
Honesdale,	'11			'02				'02	'84	'08		'63	'33		'63			'13		'04		'27				'70						3'03
Kennett Square,				'26					'70	'04		'44	'37		'76	'10		'55		'16					'35	1'08						5'08
Lansdale,		'03		'04					'67	'01		'39		'29	'67			'41	'22		'09				1'27							4'09
Mauch Chunk,	'24			'07					'92	'02		'41	'35		'49			'51	'02	'08						1'10						4'11
Ottsville,	'02			'22					'60			'13	'29		'53			'02				'28				1'28						3'59
Philadelphia, a†				'13					'45	'03		'24	'20		'27			'59	'01	'15		'27			'06	'66						3'07
Philadelphia, b,	'02			'16					'55	'02		'51	'19		'63			'66	'01	'23		'32			'10	'98						4'33
Philadelphia, c,	'04		'01	'17					'56	'03		'47	'30		'58			'68	'01	'23		'12			'11	1'23						4'74
Phoenixville,	'10			'18	'01				'48	'25		'40	'03		'73			'51	'03	'27					'12	'76						3'99
Point Pleasant,	'02			'06					'60	'03		'27	'26	'66			'82		'26		'04				'04	1'57						4'63
Pottstown,	'05			'20					'76	'04		'75		'70				'54	'26		'05				'20	'70						4'25
Quakertown,	'06			'13					'65	'05			'62		'62			'57	'33							1'13						4'16
Reading,	'01		'01	'10				'01	'58	'02		'65	'20		'69			'48	'01	'63					'04	2'16						5'59
Salem Corners,	'15			'30	'01				'93	'10		'52	'50	'50	'75			'14		'10						'70	'20					4'90
Seisholtzville,				'18					'75			'35	'25		'56			'44	'58						'05	1'16						4'32
Skippack,																																
Smith's Corner,				'07					'61	'03		'19	'14		'61			'58	'20		'06	'30			'03	'95						3'47
Swarthmore,				'02					'38			'10	'40		'90		'05		'05		'05	'15			'30	'62						3'17
West Chester,			'02	'16					'69	'03		'57	'10		'65			'59	'03	'21					'34	1'12						4'66
Westtown,				'15					'57	'02			'65‡		'70		'50		*	'25					'12	1'03						3'99
Susquehanna Basin.																																
Altoona,	'06		'04	'04					'56			'20	'31		'16			'12								'30	'03					1'82
Aqueduct,	'06		'01	'13				'20	'60	'07		'67	'26	'01	'51			'12	'11	'24					'10	1'60						4'69
Bloomsburg,	'02			'01					'60			'04	'50		'30			'05								'70						2'22
Blue Knob,	'10	'94		'30				'08	'85	'03		'50	'70		'80	'30		'14	'35				'05		'05	'70						4'97
Carlisle,	'16			'29				'01	'78			'78	'10	'10	'60			'11		'20		*				1'40‡						4'53
Drifton,	'40	'10		'20						'60	*	'20			'30	'10		*	'10	'20				'20	*		1'00					3'40
Emporium,	'20			'05				'10	'86			'67	'42		'30			'48				'05										3'08
Gettysburg,				'08	'18				'81	'08			'81	'04	'57			'14		'09						'63	'41					3'89
Girardville,																																
Grampian,	'24		'20						'18				'83		'34			'20								'15						2'14
Harrisburg,†	'02			'60					'74	'07		'50	'18	'02	'50			'58	'21	'33						'09	'72					4'56
Hollidaysburg,	'14		'12	'20				'03	'86			'60	'38		'59			'23	'11	'05					'12	'80						4'23
Huntingdon,	'15			'35					'73			'50	'35		'50					'11						'75						3'44
Kilmer,	'22			'37					'70			'86	'16		'30			'40	'21							1'35						4'57
Lancaster,				'15					'55			'35	'40		'55					'20						1'30						3'50
Lebanon,	'02			'17					'71	'03		'47	'22		'64			'30	'07	'40					'10	1'10						4'23
Le Roy,	'50			'12					'65	'06		'50	'30	'10	'50	'05		'16		'05			'01			'04						3'04
Lewisburg,	'15		'10						'61				'66		'34			'15		'12						'33						2'46
Lock Haven,	'40			'40					'22			'80	'50		'80			'02								'50						3'67
Selins Grove,				'30					'36	'09		'50	'30		'40			'25		'32						1'35						3'87
South Easton,	'13			'06					'65	'03		'57	'28		'62			'27		'04						'14						2'79
State College,	'23			'20					'58	'03		'20	'90		'40			'48								'37						3'39
Wellsboro,	'25			'05					'30	'20		'70	'40		'30			'05														2'25
Wilkes-Barre,	'35			'37	'26				'58				'72		'51			'90			'14					'65						4'50
York,				'35					'61			'45	'22		'55			'30	'11	'18		'04			'33	1'06						4'20

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Beaver Dam,	'20							'19	'74				'70		'19			'46								'19						[illegible]
Brookville,	'12			'02	'03			'06	'47	'21			1'04	'02	'23	'08		'21														[illegible]
Clarion,	'18	'01		'01	'06			'12	'47	'14			'20	'07	'35	'15		'55					'06									[illegible]
Confluence,			'46	'14				'14	'50	'10		'11	'39	'02	'32	'12		'30	'01	'27						'60	'09					[illegible]
Davis Island Dam,	'18			'05				'05	'40	'02			'70		'30	'01		'22								'70						[illegible]
DuBois,	'19	'03		'09				'09	'62				'62	'05	'26	'09										'23						[illegible]
Elwood Junction,	'10				'01			'05	'51	'04			'75		'20	'01		'37								[illegible]						[illegible]
Freeport,	'27		'02	'10	'06			'11	'52	'06			1'02	'03	'33	'06		'27						'03		'42						[illegible]
Greensboro,			'15	'08	'15			'03	'30	'03		'08	'50	'02	'45	'05		'23	'02	'12		'02				'80	'05					[illegible]
Greenville,	'10			'08					'63			'42	'15		'23								'01									[illegible]
Immel Reservoir,	'06				'25			'10	'50			'25				'20		'20								'73						[illegible]
Indiana,																																
Johnstown,	'06	'02	'31	'15			'03	'02	'70	'02	'01	'45	'17	'01	'38	'05		'18	'18	'02	'02				'06	'54						[illegible]
Kane,	'20								'76	'07		'45	'30		'50								'02									[illegible]
Ligonier,	'17			'25			'08	'05	'30				'63	'10	'30			'20	'20							'50						[illegible]
Lock No. 4,	'01		'03	'15	'10			'04	'40	'03		'02	'55	'02	'40	'03		'22								'60	'15					[illegible]
Mahoning,	'14	'01		'05	'04			'11	'76	'21			'55	'12	'35	'05		'47					'01	'02		'17						[illegible]
Meadville,																																
New Castle,	'05			'03				'30	'11			'25	'38		'19	'10		'35														[illegible]
Oil City,	'09							'06	'48	'22			1'00	'02	'30	'10		'55			'02		'10									[illegible]
Parker's Landing,	'13	'02			'05			'12	'67	'12			'80	'01	'26	'05		'48					'01									[illegible]
Pittsburg,†	'16			'31			'02	'06	'32			'62	'13		'54		'01	'19							'03	'59						[illegible]
Ridgway,					'01			'04	'43	'04			1'04	'02	'14			'64														[illegible]
Saegerstown,	'10					'80			'85			'20	'30		'40								'05									[illegible]
Saltsburg,	'16	'02		'20	'14			'07	'49	'03			'78	'08	'30	'15	'04	'19	'01							'45	'13					[illegible]
Shingle House,	'20			'03					'18	'19		'75	'20		'45	'10		'40			'07		'05									[illegible]
Smethport,	'15			'10			'50		'75	'10		'70	'30		'30			'45														[illegible]
Somerset,	'75		'21	'40	'03				'26			'65	'36		'85	'22	'21									[illegible]						[illegible]
Stoyestown,	'05		'67		'40			'18	'39	'07			'60	'30	'26	'17			'40			'05				'70	'30					[illegible]
Uniontown,	'02		'51	'30			'03		'19			'53			'06	'05		'53	'23							'90						[illegible]
Warren,				'03	'02			'09	'39	'05	'01		1'01	'03	'11	'02		'93		'01	'10	'01	'09									[illegible]
West Newton,	'10			'30	'40			'20	'40	'06			'68		'40	'20		'42	'02	'07						'42	'30					[illegible]
Potomac Basin.																																
Chambersburg,																																
McConnellsburg,																																
Lake Basin.																																
Erie,†	'19			'10				'02	'58	'09	'02	'98	'89	'04	'40	'02	'01	'20			'01											3'33

† U. S. Weather Bureau Stations. * Missing. ‡ Total for two days.

JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXXXVII. APRIL, 1894. NO. 4

THE EDSON PRESSURE RECORDING GAUGE.

[*Being the report of the Committee on Science and the Arts, adopted November 1, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 30, 1893.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the Edson Pressure Recording Gauge, finds as follows:

The instrument (*Fig. 1*) consists of a metal base A, enclosing beneath it a tempered diaphragm C, so arranged that when the fluid enters the space D, between the spring and the cap E, forming the chamber, the spring is deflected upwards.

The recording apparatus is mounted on the top of the base A, and the movement of the diaphragm C is transmitted through the arms H^2 and H^3, on the rock shaft H, by means

of the connecting bar *G*, to the vertical moving pencil carrier in front, describing about six times the original travel of the diaphragm. Simultaneously therewith, the same rock shaft *H* moves the hand M^2 before the dial *M*.

A special clock mechanism revolves the receiving reel K^2, contributing the element of time to the chart drawn from the reservoir reel *K*, on the right beneath the recording pencil.

Ordinarily this reservoir reel *K* contains a supply of charts for thirty days. A glass dome surmounting the whole allows inspection and excludes dust, moisture, etc.

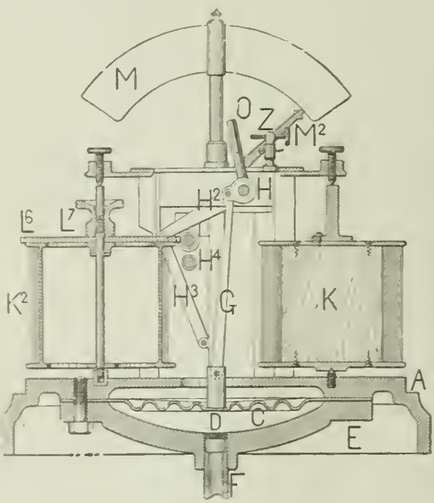

FIG. 1—Sectional view.

The supplemental adjustable arm *O*, upon the rock shaft *H*, acts as a circuit-closer for an electro-magnetic alarm, and operates a mechanical alarm usually provided with each instrument.

This style of recorder has been found successful in recording pressures from two pounds per square inch, for blast furnaces, to 1,200 pounds per square inch, used in pumping oil.

For recording temperatures of drying rooms, etc., a supplemental diaphragm is employed to increase the travel, owing to the low coëfficient of expansion of the fluids used.

The instrument has been gradually developed through more than twenty years, the first of a series of patents, covering the invention, bearing date of May 5, 1868 (No. 77,584). The present style of gauge was adopted and

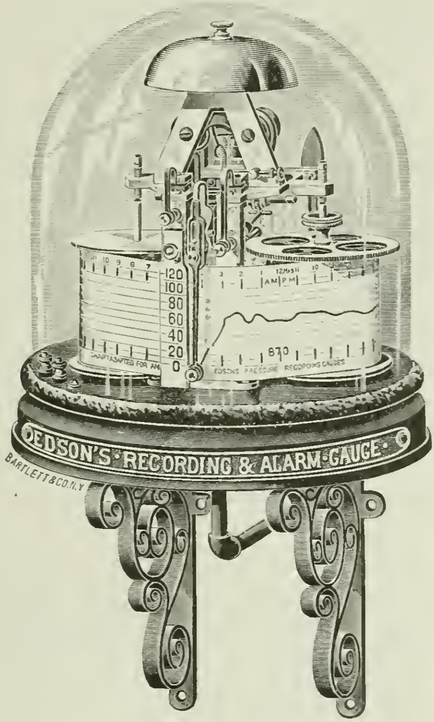

FIG. 2.

patented August 16, 1870 (No. 106,345). The latest patent bears date of December 23, 1890 (No. 443,360), and shows the most improved form of the instrument. (*Fig. 2.*)*

* It will be observed that the sectional view of the Edson gauge, shown in *Fig. 1*, exhibits some differences in details of construction as compared with the most recent form of the apparatus shown in *Fig. 2*. This may be explained on the ground that this report is, in a measure, historical in character.

The new style of instrument, above referred to, has no hand or dial, and in its construction the employment of mechanism H, H^2, H^3 and H^4 is avoided, as also the hand and dial and corresponding rack and pinion, reliance being placed upon the small vertical scale standing immediately over the chart, which is ruled precisely as the chart is, and corresponds precisely with

No other recording gauge is similar in construction, as an inspection of the appended list of letters-patent will show. This list substantially covers the ground of recording gauges, and the patents embraced therein were studied by the sub-committee appointed to conduct this investigation.

The Edson instrument affords a written tracing or log of every degree of pressure sustained within a steam boiler, tank, pipe, or any reservoir, of water, oil, air, steam or other liquid, to which it is attached, and of the time when such pressure existed. It gives, if continuously applied, a complete biography of a boiler and a correct exhibit of all the work done. The recorder is a good check on night guards, and if regularly kept, will show indisputably whether a boiler has been overstrained, and, if so, how often this has happened, the knowledge of which may save many lives and valuable property. The fact of the existence of this continuous and easily interpreted chart will undoubtedly tend to make firemen both careful and proud of their record, while giving to their employers evidence of facts not otherwise obtainable and the best assurance of careful and economical working.

When used in the water departments, the gauge not only verifies the pressure on the mains, but also detects leaks and the opening of hydrants, or any heavy draughts of water for legitimate or illegitimate purposes.

The record can be read at a glance, as the co-ordinates of time and pressure are rectangular and not circular as in

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the travel of the spring. Its indications are more accurate than those at the end of the pointer-head on the segmental arc in the old style of recorder, for the reason that some lost motion is possible in the mechanism required to change the direction of, and multiply the motion derived directly from, the diaphragm spring. The office of the Edson Recorder is not that of an *indicating* gauge, but that of a *recording* gauge. Its extreme sensitiveness, resulting from large original travel, renders its more finely graduated dial even more reliable than a large dial with a pointer-hand moving with an enormous multiplication of the original spring travel, as in other styles of gauges. In order, therefore, to simplify the instrument, and remove wearing surfaces and lost motion, as well as to reduce the first cost, the new style of instrument (*Fig. 2*), with the valuable additional feature of the electric circuit-closer, and without hand and dial, has been given the preference over the older style with hand and dial.

W. H. W.

most of the other recording gauges. The latter system does not give as clear a picture of the variations of pressure and appertaining parts of time as the former.

The Edson pressure recording gauge has been in service for many years, and a few of the testimonials submitted to the investigating committee clearly show the durability and practical value of the instruments. These testimonials without exception exhibit the fact that the gauges have done their work perfectly and to the great satisfaction of their owners, and that continuously, for periods, in some instances, up to twelve years.

Among others, the National Transit Company (oil pipe-line) has had in service, during the last six years, about 140 of the Edson instruments, one-half of which are recording from 0 to 800 and as high as 1,500 pounds per square inch. With but one exception, none of these have ever been returned for repairs. The Illinois Steel Company has in constant operation forty-five gauges. The list of the patrons of the Edson pressure recording gauge is very long, and the best names are among them, and their evidence as to the efficiency and practical value is, uniformly, highly favorable.

It can, therefore, safely be affirmed that the Edson gauge has proved itself in service to be a reliable and well-made instrument, which has successfully stood the severe test of time, and it can safely be recommended to every owner of a steam boiler in the interests of safety and economy.

The recording gauge shows its superior qualities not only in connection with the steam boiler, but also in all cases where fluids are kept under pressure. It is, therefore, very desirable to use in connection with gas and water-pipe systems, oil-pipe lines and tanks, blast furnaces, etc.

Its extremely close accuracy makes this gauge very valuable in the various industries where uniformity of pressure is indispensable for the best production and highest efficiency of a manufacturing or other plant.

The gauge is mechanically one of the finest pieces of workmanship of its class now in the market, and the fact that it can be used continuously, that is, that it need

not be looked after every day, makes it particularly desirable where it would be inconvenient to change records every twenty-four hours; and the user can be assured that the records will continue in a legible shape whether it receives proper attention or not, which, of course, cannot generally be done in the case of gauges making a circular record.

A large amount of labor has been spent in the perfection of this gauge during the many years that it has been in use, and the fact that the gauge as now made is such an excellent piece of apparatus, warrants the Institute in recommending the award of the John Scott Legacy Premium and Medal to the inventor, Mr. Jarvis B. Edson, for the excellent development of his pressure recording gauge.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, November 1, 1893.

JOSEPH M. WILSON, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by
H. R. HEYL, *Chairman.*

APPENDIX.

LIST OF UNITED STATES PATENTS BEARING ON THE SUBJECT OF RECORDING GAUGES, AND CONSULTED IN THIS INVESTIGATION.

Rice, No. 7,583, August 20, 1850.
Krausch, No. 36,411, September 9, 1862.
Wiegaud, LeVan, No. 41,182, January 5, 1864.
Davis, No. 66,307, July 2, 1867.
Peelor, No. 113,693, April 11, 1871.
Davis, No. 152,467, June 30, 1874.
Robinson, No. 169,660, November 9, 1875.
Thomson, No. 232,156, September 14, 1880.
Stowe, No. 234,086, November, 2, 1880.
Brouardel, No. 242,260, May 31, 1881.
Thissell, No. 253,786, February 14, 1882.
Jonson, No. 265,327, October 3, 1882.
Bernstein, No. 268,383, December 5, 1882.
Jones and Glines, No. 287,684, October 30; 1883.
Jones, No. 287,685, October 30, 1883.
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Richard, No. 334,613, January 19, 1886.
Shedlock, No. 336,668, February 23, 1886.
Jones, No. 340,581, April 27, 1886.

Jones, No. 343,177, June 8, 1886.
Jones, No. 344,448, June 29, 1886.
Jones, No. 345,061, July 6, 1886.
Jones, No. 348,219, August 31, 1886.
Hambleton, No. 360,291, March 29, 1887.
Hambleton, No. 389,635, September 18, 1888.
Tata, No. 408,938, August 13, 1889.
Wills, No. 409,891, August 27, 1889.
Sporton White, No. 410,214, September 3, 1889.
Herschel, No. 417,245, December 17, 1889.
Schroyer, No. 426,144, April 22, 1890.
Williams, No. 447,594, March 3, 1891.
Ayton, No. 459,863, September 22, 1891.
Seiler, No. 481,287, August 23, 1892.

[*Abstract.*]

On the MAXIMUM CONTEMPORARY ECONOMY of the HIGH-PRESSURE MULTIPLE-EXPANSION STEAM ENGINE.*

By Robert H. Thurston, LL.D.,
Director of Sibley College, Cornell University. Past President, A.S.M.E.

The paper, of which the following is an abstract, includes an account of the investigation of the economical performance of a triple-expansion steam pumping engine, designed by Mr. Irving Reynolds, in consultation with Mr. Edwin Reynolds, and built by the E. P. Allis Company, of Milwaukee, under a contract with that city; which engine is now in operation at the North Point Station, supplying the city with water from Lake Michigan. Its exceptional economy and high duty were revealed, originally, by the result of the customary "contractor's trial," made to determine whether the terms of the contract had been fufilled † and whether its acceptance by the city, with payment as

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* Presented at the New York Meeting (December, 1893), of the American Society of Mechanical Engineers, and forming part of Volume XV, of the *Transactions.* Abstract prepared by the author especially for the *Journal of the Franklin Institute.*

† The guarantee was a duty of 125,000,000, with 100 pounds of anthracite coal.

agreed, should be carried out. The results of the trials made later, especially those made by the Sibley College staff, confirmed the first impression, that this engine illustrates the maximum contemporary economy of the high-pressure multiple-expansion steam engine, and the publication of this paper probably establishes this as "breaking the record" to date, and fixing the limit of efficiency of the best existing engines nearer the ideal figure than it has ever before been brought. The Milwaukee engine demands but about twenty-five per cent. more heat, steam and fuel, when doing its best work, than would the representative ideal engine, the purely thermo-dynamic machine, operating under the same physical conditions and in the same manner, as to steam distribution, as the real engine. The real engine has about seventy-five per cent. of the efficiency of the ideal. It is this fact which makes the information here presented to the reader interested in steam engineering in any of its aspects so exceptionally important. An engine which brings down the consumption of energy of heat and steam and fuel to the equivalent of 13,056 B.T.U. per hour, 217 per minute, per horse-power, to 11·678 pounds of dry steam per horse-power per hour, and to 1·25 or 1·35 pounds of fuel, giving an actual duty, watch by watch, for twenty-four hours, of 140,000,000 to 150,000,000 per 100 pounds of fuel actually consumed, with but moderate efficiency of boiler, and averaging the equivalent of 154,048,000 foot-pounds per 1,000 pounds of dry steam at the engine, not only establishes a wonderful record, but marks off an era in the progress of the steam engine. This is probably about the limit for the century, and twelve pounds of steam per horse-power per hour, a figure now known to have been approximated by several engines, may be taken as the culmination of the progress of the nineteenth century. The following abstract gives the essential facts presented in this paper, relative to this interesting and important case.

The maximum contemporary economy of the steam engine of the time has now so nearly approached the computed efficiency of its ideal thermo-dynamic representative, under similar external working conditions, that it has

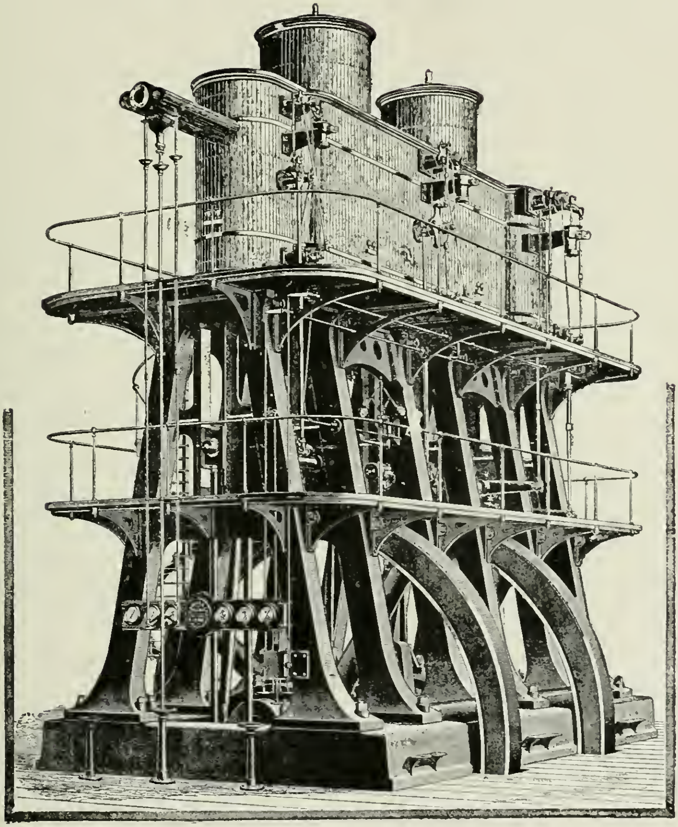


FIG. 1.—Milwaukee Triple-expansion Pumping Engine.

[From Thurston's *Manual of the Steam Engine.* John Wiley & Sons, New York.]

come to be admitted that the distance separating them, a consequence of the unavoidable and almost irreducible wastes to which the former is subject, and from which the latter is free, although still growing less, is exceedingly difficult of further reduction. The closer the approximation of the real to the ideal, the more difficult it is to further improve the machine, and the more certain it is that any considerable and rapid gain is out of the question. We have, for a century, been constantly changing the conditions exterior to the machine, in such manner as to raise the maximum efficiency of the ideal case as steadily higher and make it more difficult of attainment by the real engine; while we have as constantly and steadily reduced the defects of the latter in such manner as to make the approximation of the real to the ideal closer and closer, in spite of these obstructive circumstances. Perhaps the best view of these changing conditions and performances may be obtained by the observation of the continual gain exhibited in its history, since the days of Watt or of Newcomen, in the magnitude of the technically so-called "duty" of steam pumping engines.

With improving thermo-dynamic conditions and decreasing wastes in the engine, starting from the 5,000,000 duty of the Savery engines still existing in the time of Watt, the 12,000,000 of Smeaton's Newcomen engine of the same period, and the first figures of Watt, perhaps averaging 20,000,000 foot-pounds per 100 pounds of fuel; and tracing the improvement through the most flourishing period of Watt's work, when he attained about 30,000,000, and his final perfection of the later Cornish engines, which, still later, attained in ordinary operation 60,000,000 to 80,000,000, we come to the period, beginning with 1860, of the successful introduction of modern forms of the high-pressure multiple-expansion pumping engine, giving duties ranging up to about 100,000,000 to 110,000,000, and to 120,000,000 in the succeeding generation and to date.

* * * * * * *

The history of this case is briefly as follows: The attention of the writer was first called to this remarkable engine

by Mr. E. D. Leavitt, who, in December, 1892, reported its performance as 12·15 pounds of water per horse-power per hour, and suggested obtaining from its designer and builders the facts relating to the plant, with a view to publication in the interests of science and of the profession. Acting at once upon this suggestion, the writer secured permission from the City Engineer's office, and from the builders and the designers of the engine, to make a special duty-trial of the machine, in the interest of all concerned and of the profession especially. The trial was to be made by the Sibley College staff, as a part of the year's work of the Department of Experimental Engineering, with every facility that either the proprietors, the builders, or Cornell University and Sibley College, could furnish. The results were to be worked up in the Sibley College laboratories, reported by the college to the designers, builders, and users of the engine, and published as soon as practicable by the writer, acting for the parties interested.

It was proposed that the trial should be made during the Easter vacation of the college, by a party to be selected, organized, and directed by Prof. R. C. Carpenter, and to include such skilled and trained observers as could best be secured from his own department, re-enforced by observers sent in by the City Engineer and by the Allis Company. Among the "crew" sent out from Ithaca were several men engaged in graduate work, seeking material for their "Masters' theses," and some undergraduates; all of whom had enjoyed exceptional opportunities and shown great skill and efficiency in work of this kind. The special desire of the writer was to secure such data as would serve for a comparison of the theoretical ideal and the real engine, such as is here attempted, which comparison had never before been made in precisely this manner or with what it was hoped would prove such unexampled completeness.

This trial was finally made as proposed, and the results proved to be even more striking and satisfactory than had been claimed by the builders or reported to the writer. The data and observations are preserved in the files of the Sibley College laboratory.

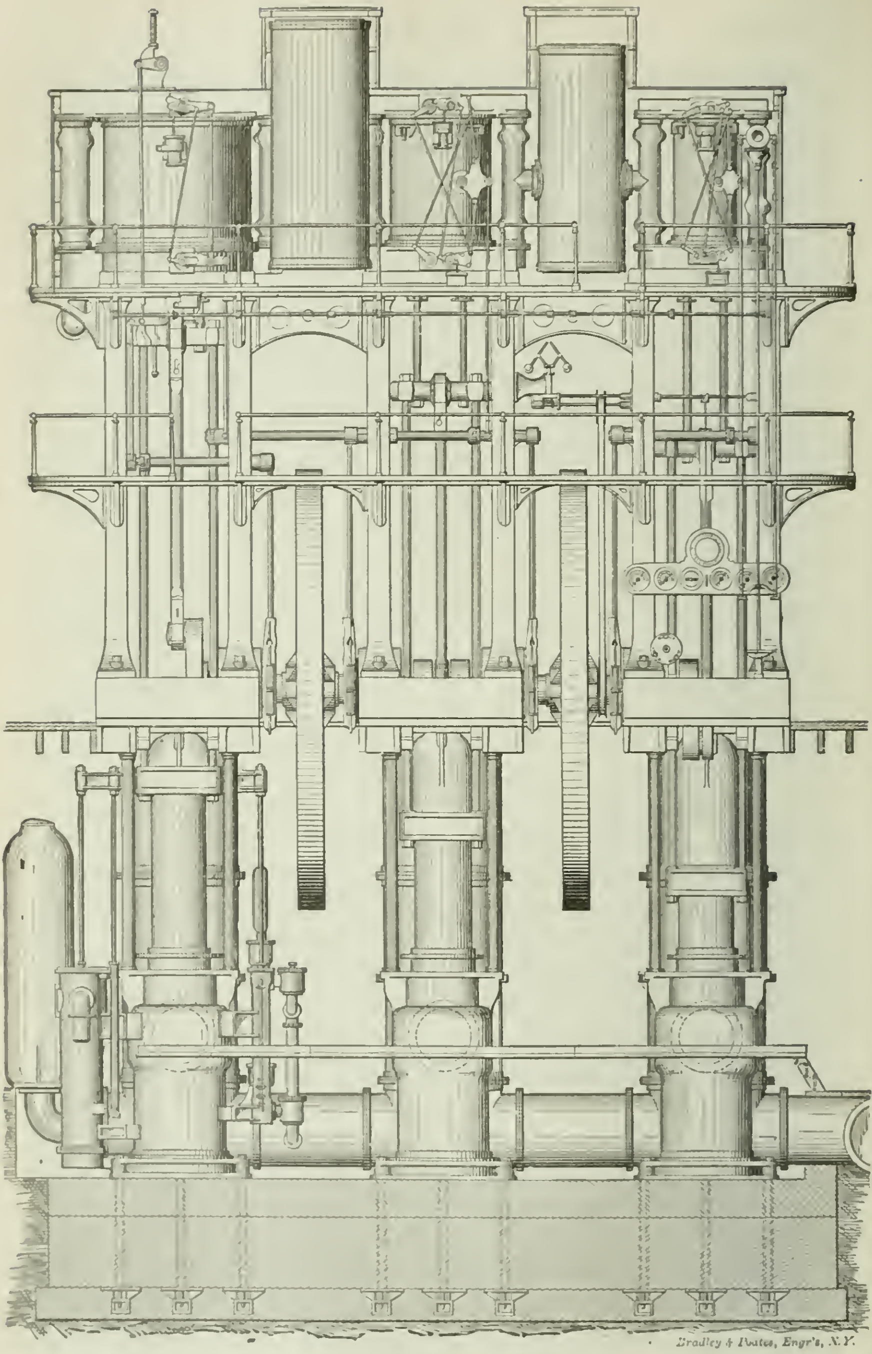
* * * * * * *

The Milwaukee engine is of the vertical triple-expansion type, with steam cylinders and parts above the bed-plate, arranged somewhat similar to those of the modern marine engine (*Figs. 1, 2, 3*). The capacity of the engine is 18,000,000 gallons in twenty-four hours, raised 160 feet, and the speed is 20 revolutions per minute, or 200 feet piston speed. The cylinders are three in number, one high-pressure, 28 inches diameter, one intermediate, 48 inches, and one low-pressure, 74 inches diameter, all having a stroke of 60 inches. The cylinders are mounted on cast-iron A frames, which rest on heavy bed-plates carrying the main shaft journals. The cylinders are steam-jacketed, having the working barrels inserted separate as "liners." The steam and exhaust valves are located in the cylinder-heads, their chests thus jacketing the latter.

The pumps are entirely below the floor. The fly-wheels perform the office simply of aiding in the regulation of the engine. Between each two cylinders is a receiver, heated by high-pressure steam. The volumes are, respectively, high pressure, 101·3 cubic feet; intermediate, 151 cubic feet. In the high-pressure and intermediate cylinders the jackets are supplied with live steam at boiler pressure; but on the low-pressure cylinder the jacket is supplied with steam which passes through a reducing valve, and which has a constant pressure of thirty-four pounds. The steam is supplied to the high-pressure jacket by a pipe leading directly from the main steam-pipe; the exhaust from this jacket supplies the jacket of the intermediate cylinder, and this is led into a trap, the overflow of which ordinarily passes into the suction of the feed-pump for supplying the boilers. The exhaust steam from the low-pressure cylinder jacket is similarly received into a steam-trap and discharged into a feed-pipe.

The exhaust valves of the low-pressure cylinders, when closed, are flush on the inside of the cylinder head, thus eliminating clearance due to exhaust ports. All the valve ports are located in the cylinder heads.

The valve gear is of the Corliss type on the high and intermediate cylinders, and a combination of Corliss steam valves and poppet exhaust valves on the low-pressure cylin-



Bradley & Poates, Engr's, N.Y.

FIG. 2 —Front view of engine.

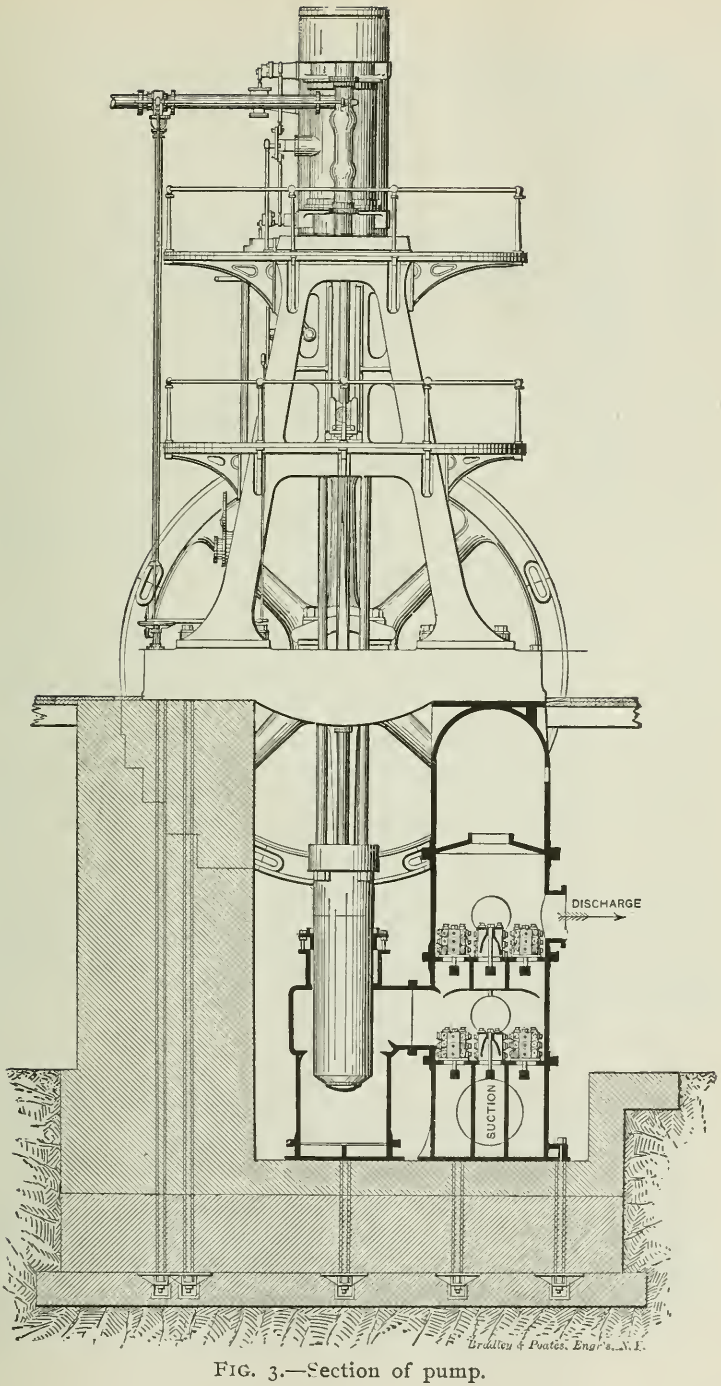


FIG. 3.—Section of pump.

der. The clearances in the cylinders and ports are: H.P., $1\frac{4}{10}$ per cent.; I.P., $1\frac{5}{10}$ per cent.; L.P., $\frac{77}{100}$ of one per cent.

* * * * * * *

The pumps are three in number, one located beneath each engine. The plungers (thirty-two inches diameter) are of the single-acting outside-packed plunger type, each plunger being driven from a crosshead. The valve chambers are cylindrical, and extend above the discharge valves, forming air chambers, on which rests one end of each of the engine bed-plates, reducing the cost of the foundations, and at the same time rendering the pumps easily accessible. The pump valves are rubber, of small diameter (three and one-half inch), and are mounted in groups of twenty-eight, on "cages." There are seven of these cages (196 valves) in the suction and discharge of each pump, with a total area about equal to that of the plunger.

The engine is fitted with a surface condenser, the air, feed, and circulating pumps being driven by an arm extended from the low-pressure plunger. The air pump is 22 inches diameter by 60 inches stroke, and is single-acting.

Steam is supplied by a battery of five horizontal, tubular, externally fired boilers, with ordinary brick setting. Four boilers are ordinarily used, though three are ample for supplying this engine, four readily supplying steam for an additional 12,000,000 engine in the same building. The boilers are 66 inches diameter by 18 feet long, each containing 55 four-inch tubes, and having about 1,200 square feet of heating surface.

* * * * * * *

The contractor's trials of this triple-expansion engine were made in July, 1892, by Messrs. Benzenberg and Lewis; the first to determine the capacity of the engine, the second to secure a record of its maximum economy.

The following are the figures officially reported, and upon these the engine was accepted by the city of Milwaukee. Its regular work began August 23, 1891.

CONTRACTOR'S TRIALS, TRIPLE-EXPANSION PUMPING ENGINE.

	1892.	
Date of trial,	July 12, 13	July 20
Duration, hours,	24	24
Total revolutions of engine,	29,566	29,524
Revolutions per minute,	20·532	20·503
Average steam pressure by gauge,	125·8	125·33
Average vacuum pressure by gauge,	13·794	13·75
Average first receiver pressure by gauge,	28·17	29·83
Average second receiver pressure by gauge,	0·406	1·10
Barometer, inches,	27·99	—
Total head of water pumped against,	153·56	—
Average temperature of feed water, F.,	130°	132°·2
Total coal burned (Anthracite, egg),	18,700	19,200
Total ashes,	2,690	3,187
Per cent. of ashes and refuse,	14·385	16·6
Actual evaporation per pound of coal,	8·76	8·758
Equivalent evaporation from and at 212°,	9·91	9·89
Coal per square foot of grate per hour,	—	7·5
Total number of gallons pumped, by plunger displacement,	18,528,657	—
Average indicated horse-power,	557,029	576,449
Total weight of feed water	—	168,163
* Feed water per I.H.P. per hour,	—	12·155
Coal per I.H.P. per hour,	—	1·387
Duty per 100 pounds of coal burned, foot-pounds,	126,865,240	—
Duty on supposition that evaporation was 10·27 from and at 212°, foot-pounds,	132,950,524	—
Duty as above if coal contains 3 per cent. water,	136,900,000	—

* No correction for moisture.

That this exceptional duty is not the result of accidental and fortunate concurrence of favorable conditions is proven by the fact that several other engines of similar design have closely approximated these figures. Thus, the trial of the three Chicago engines, by Messrs. R. W. Hunt & Co., has since given the following:*

RESULTS OF CONTRACTOR'S TRIAL OF CHICAGO PUMPING ENGINES, JULY, 1893.

Aggregate delivered horse-power,	1031·47
Mechanical efficiency,	0·9143
Aggregate indicated horse-power,	1128·15
Feed water per delivered horse-power per hour,	13·267

* Report to City Engineer of Chicago, July 5, 1893.

Feed water per indicated horse-power per hour, pounds, ...	12·13*
B.T.U. per delivered horse-power per minute, ...	244·6
B.T.U. per indicated porse-power per minute, ...	223·7
Indicated horse-power per square foot of upper grate (H furnace),	12·82
Heating surface per indicated horse-power, ...	4·35
Foot-pounds per 1,000 pounds of feed water (contract basis), . .	148,958,000
Foot-pounds per 1,000,000 B.T.U., ...	134,643,030
Foot-pounds per 100 pouuds of bituminous coal, ...	118,022,900
Foot-pounds per 100 pounds of combustible, ...	128,852,500

* Equivalent, with one per cent. entrained water, to 12·03 pounds.

* * * * * * *

The Sibley College trials were inaugurated March 23d, by a preliminary organization of the crew and a practice test of several hours' duration, in which the observers were given a drill in their assigned work. The engine was examined and inspected in every part, and the whole system of apparatus was tested, to ascertain its fitness for the purposes in view.

All arrangements being found satisfactory, the final trial was proceeded with, March 25th, at 9 A.M.; was continued uninterruptedly twenty-four hours; was commenced and ended to the satisfaction of all four sets of observers, and was so certified by the representatives of the city of Milwaukee, of the builders, of the delegate from R. W. Hunt & Co., and by the official representative of Sibley College.

The weight of water delivered was computed from the plunger displacement, and the total weight for each revolution of the engine was 5229·29 pounds.* The average head pumped against was 161·84 feet. The head was measured by a pressure gauge connected to the discharge chambers of the pumps.

* * * * * * *

* This is a standard method, and was, in fact, the only method practicable at the time. The writer would always check by the use of a weir, when possible; but, in this case, the construction of the pumps was such as to make sensible slip improbable, and the pump cards are so sharp at the corners as to indicate that they ran full. The writer made a visit to Milwaukee and personally examined the engine, to satisfy himself of the fact that the valves act promptly and efficiently. Experiment, later, on an engine of similar construction, gave a slip of 0·0073. It may be taken here as undoubtedly less than one per cent.

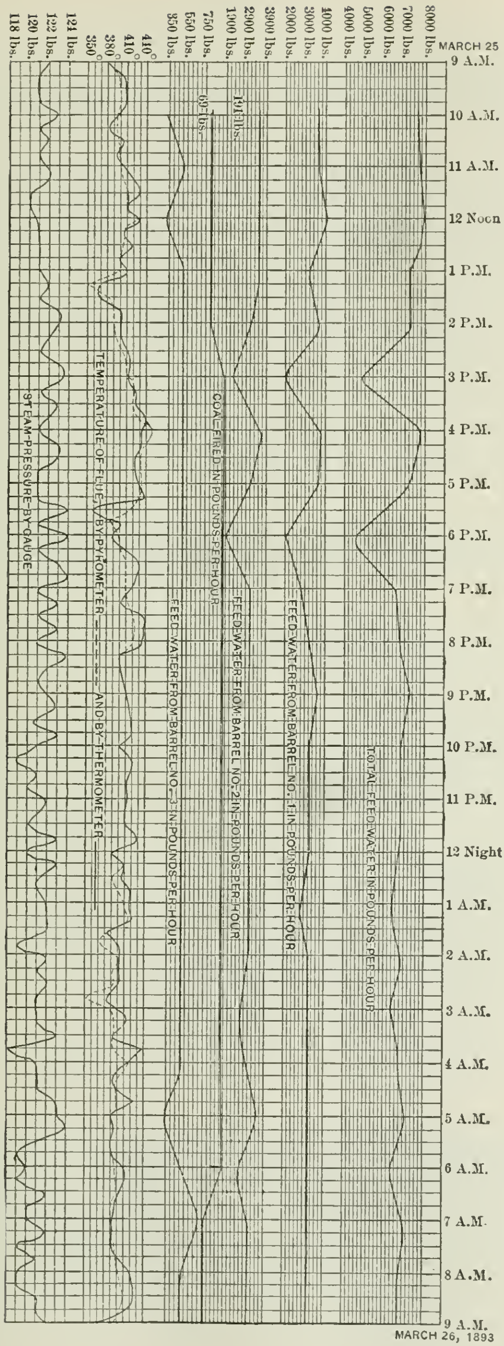


FIG. 4.—Graphical log.

The data, logs and results of this trial are given in the Appendix, and the details of the work in the report made to the builders.* They are admirably summarized in the accompanying "graphical log." As there shown, the indicated horse-power was 573·87, divided among the cylinders thus: High-pressure, 175·39; intermediate, 169·62; low-pressure, 228·86. The gauge pressures were, at the high-pressure cylinder, 121·46; first receiver, 32·43; second receiver, 1·5. The total water evaporated into dry steam was 6700·7 pounds per hour, *equivalent to 11,678 pounds per I.H.P. per hour.* The useful work computed from the pressures and volume of water delivered was 520·06 D.H.P. The friction of the engine was 52·92 H.P., 9·22 per cent. of the I.H.P.

A special test, made April 7, 1893, determined the heat rejected into the condenser, resulting as below:

Average revolutions per minute,	20·41
Average steam pressure, gauge, pounds,	121·6
First receiver pressure,	31·9
Second receiver pressure,	1·67
Vacuum below atmosphere, inches,	13·5
Temperature of ejector water,	40° F.
Temperature of discharge water,	98° F.
Depth over weir, twelve-inch notch, feet,	0·2669
Cubic feet per minute,	26·78
Pounds of injection water per minute,	1,660
Pounds of feed water per minute,	111·6
Ratio injection water to feed water,	14·9
Per cent. of heat carried off in jacket water,	9·25
Per cent. of heat carried off in exhaust,	75·10
Per cent. of heat carried off in discharge water,	15·65
Probable quality of steam in exhaust from low-pressure engine, per cent.,	84·3

The net result of the whole investigation is seen to be the establishment, by standard methods of contemporary practice, of the highest record of steam-engine duty yet obtained as the outcome of such exact methods of research.

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* *Sibley Journal of Engineering*, June, 1893.

The useful work performed, measured as "duty" by the accepted standards, is:

Foot-pounds of work for 100 pounds dry coal, ...	143,306,470
Foot-pounds of work for 100 pounds wet coal, ...	135,770,000
Foot-pounds of work for 100 pounds combustible, . . .	145,438,000
Foot-pounds of work for 1,000 pounds feed-water, . . .	152,448,000
Foot-pounds of work for 1,000 pounds dry steam, . . .	154,048,000
Foot-pounds of work for 1,000,000 B.T.U., ...	137,656,000
Foot-pounds of work for one hundredweight coal (112 pounds), ...	152,630,000
Kilogrammeters of work per kilo of coal, ...	429,110

The thermo-dynamic results are:

Thermo-dynamic efficiency, ...		0·194
Heat per I.H.P. per hour, and per minute, B.T.U.,	13,056	217·6
Steam per I.H.P. per hour, pounds, ...		11·678
Fuel per I.H.P. per hour, pounds, ...		1·237
Heat per D.H.P. per hour, and per minute, B.T.U.,	14,382	239·7
Steam per D.H.P. per hour, pounds, ...		12,864
Fuel per D.H.P. per hour, pounds, ...		1·364

Were these engines attached to boilers evaporating ten pounds instead of nine, the fuel-rate would be, per I.H.P., 1·168 pounds, and per D.H.P., 1·286, or about $1\frac{1}{6}$ and $1\frac{1}{4}$ pounds, respectively.

The efficiency above given is 0·668, or two-thirds, that of a Carnot cycle working through the same range of temperatures and pressures. It is equal to $0{\cdot}194/0{\cdot}252 = 0{\cdot}77$ of the thermo-dynamic efficiency for the Rankine cycle of the ideal case.

* * * * * * *

The distribution of the energy supplied to the engine, during the trial, can now be readily determined for comparison of the real with the ideal case. The ideal engine, under similar circumstances, would have an efficiency of about 0·25, and would require 9·25 pounds of steam, nearly a pound of fuel per horse-power per hour. We find, from the records of the trial, that of all the energy developed in the cylinders,

9·22 per cent. was wasted in friction. In summary, we obtain the following figures:

DISTRIBUTION OF ENERGIES.

Part of Total Energy Supplied.	Per Cent.	Per D.H.P. per Hour.	
		B.T.U.	Pounds Steam.
Thermal and thermo-dynamic wastes,	80·57	11587·51	10·455
Dynamic, or friction, waste,	1·73	248·81	0·222
Useful work,	17·70	2545·61	2·187
Total thermo-dynamic transformation,	19·43	2794·42	2·409
Total from boilers,	100·00	14,382	12·864

APPENDIX.

Dimensions, Logs, Data and Results of Trial of the Milwaukee Pumping Engine.

DIMENSION OF BOILERS.

Length,	18 ft.
Diameter,	66 ins.
Grate,	5 ft. long, 5 ft. 4 ins. wide.
Grate surface,	26·65 sq. ft.
Tubes in each boiler, 55,	diameter 4 ins.
Area of tubes in each boiler,	4·68 sq. ft.
Water-heating surface,	1,216 sq. ft.
Ratio of heating to grate surface,	35
Height of chimney,	125 ft.
Area of chimney,	12·566 sq. ft.
Total grate surface of the four boilers,	106·6 sq. ft.
Total heating surface,	4864·0 sq. ft.
Bottom of gauge glass to bottom of boiler shell,	3 ft. 1½ ins.

BOILER TEST.

Duration of test,	24 hrs.
Barometer, inches of mercury,	29·54
Atmospheric pressure, pounds per square inch,	14·5
Steam gauge, corrected (at engine),	121·6
Draft gauge, inches of water,	0·4025
Absolute steam pressure,	136·1 lbs.
External air, temperature degrees F.,	25·71
Boiler room, temperature degrees F,	50
Flue, { Thermometer in top, degrees F.,	406·02
Flue, { Pyrometer in centre, degrees F.,	403·02
Feed water,	97
Steam,	350·6

Fuel.

Total coal consumed, pounds,	18,234
Moisture in coal, per cent,	5·25
Dry coal consumed,	17,277
Total ash, dry, pounds,	255
Total ash, dry, per cent. of dry coal,	1·47
Moisture and ash, per cent. of wet coal,	6·65
Total combustible, pounds,	17·022

Fuel per Hour, Pounds.

Actual,	759·75
Dry coal,	719·84
Combustible,	709·25
Actual coal per square foot of grate,	7·15
Dry coal per square foot of grate,	6·76
Combustible per square foot of grate,	6·65

Calorimeter.

Temperature of steam in calorimeter, degrees F.,	284·6
Back-pressure in calorimeter, inches of mercury,	1·9
Quality of steam,	98·95
Per cent. of entrained water,	1·05
Number of minutes calorimeter was open,	114
Steam used in calorimeter, pounds,	208·5

Feed Water.

Total weight of water used, pounds,	162,864
Excess of water in boiler at end of run, pounds,	131
Total evaporated dry steam, pounds,	161023·2
Factor of evaporation. (Equivalent value of one pound wet steam to one pound dry steam from and at 212° F.)	1·154
Total equivalent evaporation from and at 212° F., pounds,	187,794

Feed Water per Hour, Pounds.

Actual amount used, pounds,	6780·5
Evaporated dry steam,	6709·4
Equivalent evaporated from and at 212°,	7,710

Evaporation per Pound of Coal, Pounds.

* Apparent, feed water 97°, steam 121·4,	8·906
† Actual to dry steam,	8·81
Equivalent from and at 212°,	10·27

Evaporation per Pound of Dry Coal, Pounds.

* Apparent, feed water 97°, steam 121·4,	9·425
Equivalent from and at 212°,	10·72

Evaporation per pound of Combustible, Pounds.

* Apparent, feed water 97°, steam 121·4,	9·56
Equivalent from and at 212°,	10·88

* Uncorrected for calorimeter.

† Corrected for calorimeter.

Evaporation per Hour—Per Square Foot of Grate.

Actual, uncorrected for moisture, pounds, ...	63·6
Equivalent from and at 212°, pounds, ...	73·2

Per Square Foot of Water-heating Surface.

Actual, uncorrected for moisture, pounds, ...	1·505
Equivalent from and at 212°, pounds, ...	1·73

Per Square Foot of Least Draft Area.

Actual, uncorrected for moisture, pounds, ...	373
Equivalent from and at 212°, pounds, ...	429

Horse-power.

On basis of 30 pounds, from 100° F. to 70 pounds pressure, . .	223·5
Builder's rating, ...	400
Ratio of boiler horse-power to capacity, per cent., ...	55·7

Efficiency of Boiler.

(*A*) Heat generated per hour on basis of 14,500 B.T.U. per pound of combustible, ...	10,285,125
(*B*) Heat absorbed by steam per hour, B.T.U., ...	7,554,833
Efficiency of boiler, (*A*)÷(*B*), per cent., ...	73·45

TRIPLE-EXPANSION PUMPING ENGINE.

Dimensions.

Length of stroke of each piston, ...	60 ins.
Diameter of high-pressure cylinder, ...	28 ins.
Diameter of intermediate-pressure cylinder, ...	48 ins.
Diameter of low-pressure cylinder, ...	74 ins.
Diameter of piston rod in each cylinder, ...	4 ins.
Number of piston rods in each cylinder, ...	6
Clearance of high-pressure cylinder per cent., ...	1·4
Clearance of intermediate-pressure cylinder, per cent., . .	1·5
Clearance of low-pressure cylinder, per cent., ...	0·77
Volume of first receiver, ...	101·3 cu. ft.
Volume of second receiver, ...	181 cu. ft.
Number of reheater pipes, first receiver, ...	57
Number of reheater pipes, second receiver, ...	35
Diameter of reheater pipes, ...	2 ins.
Number of single-acting water plungers, ...	3
Diameter of each, ...	32 ins.
Diameter of single-acting air pump, ...	20 ins.
Diameter of single-acting plunger feed pump, ...	2¼ ins.
Diameter of single-acting air compressing pump, ...	2¼ ins.
Diameter of double-acting circulating pump, ...	7½ ins.
Stroke of all pump plungers, ...	60 ins.
Distance from centre of pressure gauge to centre of pump chamber, ...	19·8 ft.
Distance from bottom of well to centre of pump chamber, . .	20 ft.

Area of Piston, Square Inches.

	Top.	Bottom.
Area of piston, high pressure, ...	615·745	590·621
Area of piston, intermediate pressure, ...	1809·562	1784·429
Area of piston, low pressure, ...	4300·85	4275·72
Area of each pump plunger, ...	804·2496 sq. in.	5·585 sq. ft.
Total volume delivered per revolution by one plunger, . . .		27·9253 cu. ft.
Total volume delivered per revolution by three plungers, . .		626·688 gals.
Total weight delivered per revolution by three plungers, . .		5229·291 lbs.

ENGINE TEST—*Results and Data.*

Duration of test, ...	24 hrs.

Average Temperatures.

Water at pump well, F., ...	34°
Feed water to boiler, ...	97
Discharge from air pump, ...	105·4
Calorimeter (1·9 inches back-pressure), ...	284·5
Engine room, ...	69·9
External air, ...	25·71

Average Pressures

Barometer, inches, ...	29·54
Barometer, pounds, ...	14·5
Gauge at throttle, ...	121·45
Absolute pressure at engine, ...	135·94
Vacuum gauge, pounds, ...	13·84
First receiver gauge, pounds, ...	32·43
Second receiver gauge, pounds, ...	1·3
High-pressure jacket, pounds, ...	121·40
Low pressure by gauge, pounds, ...	56·47
Suction head by float, feet, ...	10·77

Revolutions.

Total number, ...	29,252
Per hour, ...	1218·8
Per minute, ...	20·314
Quality of steam, per cent., ...	98·95
Moisture in steam, per cent., ...	1·05

Feed Water and Dry Steam.

Total feed water to boiler, pounds, ...	162,864
Excess in boilers at end of run, pounds, ...	131
Steam used by calorimeter (114 min.), pounds, ...	208·5
Total wet steam to engine, ...	162524·5
Total dry steam to engine, ...	160818·1
Wet steam to engine per hour, ...	6771·8
Dry steam to engine per hour, ...	6700·7
Heat in one pound wet steam above 105·4 F., B.T.U., ...	1106·26
Heat supplied to engine per hour, B.T.U., ...	7,493,444
Heat supplied to engine per minute, B.T.U., ...	124890·7

Total wet steam used in jackets,		15,054
Wet steam used in jackets per hour,		627·3
Per cent. of total steam used by jackets,		9·25

Indicated Horse-power.

High-pressure cylinder,	Top,	87·54
	Bottom,	87·85
		175·39
Intermediate,	Top,	88·84
	Bottom,	80·78
		169·62
Low,	Top,	116·23
	Bottom,	112·63
		228·86
Total,		573·87
Delivered horse-power,		520·96
Friction horse-power,		52·91
Friction horse-power, per cent.,		9·22
Dry steam per I. H. P. per hour,		11·678
B.T.U. per I.H.P. per minute,		217·6

Relative Volumes of Cylinders.

High-pressure,	1	1
Intermediate,	2·95	3·01
Low,	6·95	7·01
Total number of expansions,	19·55	

PUMP TEST.

Duration,	24 hrs.
Temperature of water pumped, F.,	34°
Weight per cubic foot,	62·42
Pounds of water lifted per revolution,	5229·2917
Water pressure in pounds,	56·473
Delivery head in feet,	131·275
Distance from delivery gauge to centre of pump, feet,	19·8
Suction head in feet,	10·77
Total head in feet,	161·845
Revolutions per hour,	1218·8
Foot-pounds of work per hour,	1,031,520,000
Kilogrammeters per hour,	142,556,000
Wet coal per hour, pounds,	759·75
Dry coal per hour, pounds,	719·8
Kilograms of coal per hour,	332·23
Combustible per hour, pounds,	709·25

Duty.

Foot-pounds of work for 100 pounds of dry coal,	143,306,470
Foot-pounds of work for 100 pounds of wet coal,	135,770,000
Foot-pounds of work for 100 pounds of combustible,	145,438,000

Foot-pounds of work for 1,000 pounds of feed-water, ...	152,448,000
Foot-pounds of work for 1,000 pounds of dry steam, ...	154,048,000
Foot-pounds of work for 100,000,000 B.T.U., ...	137,656,000
Foot-pounds of work for one hundredweight coal (112 pounds),	152,630,000
Kilogrammeters of work per kilo of coal, ...	429,110

Capacity.

Cubic feet per revolution 3 × 27·9253, ...	83·7759
Gallons per revolution, ...	626·688
Cubic feet per hour, ...	102112·5
Gallons per hour, ...	763,807
Cubic feet for 24 hours, ...	2,450,940
Gallons for 24 hours, ...	18,331,364

PRINCIPAL QUANTITIES OF BOILER AND PUMP TEST FOR EACH WATCH OF FIREMAN.

Number of Watch.	*A.*	*B.*	*C.*	*D.*	*Total or Averages.*
Duration of hours, ...	5	8	8	3	24
Coal fired, ...	3,591	6,284	6,284	2,075	18,234
Coal per hour fired, ...	718	785·5	785·5	691·60	759·75
Estimated excess in furnace, ...	—35	110	150	45	—
Coal per hour burned, ...	725	775	776	730	—
Dry coal (cor. 5·25 per cent.), ...	688	735	736	693	719·8
Temperature feed water, ...	—	—	—	—	—
Steam pressure at engine, ...	121·43	122·14	121·29	120·41	121·46
Barometer, inches, ...	29·55	29·53	29·52	29·577	29·537
No barrels water per watch :					
Bbl. No. 1 net wt. 400¼	45	60	63	24(—20)	192—20
Bbl. No. 2 net wt. 386¾	45	60	62	24	191
Bbl. No. 3 net wt. 173½	13⅙	24	23	10	70⅙
Wt. of water, Bbl. No. 1, ...	18,011	24,016	25,216	9,586	—
Bbl. No. 2, ...	17,016	23,595	23,978	9,282	—
Bbl. No. 3, ...	2,874	4,164	3,591	1,735	—
Total feed water.	37,301	51,775	53,185	20,603	162,864
Excess in tank, end watch, ...	785	750	300	—	—
Excess in boilers (change in ht. on gauge glass, in.), ...	1·75	0·16	—0·215	0·08	—
Excess in boilers, pounds, . .	2,667	259	—365	131	131
Total evaporation during watch, . .	33,849	54,218	54,357	20,517	54,354
Evaporated per hour, ...	6,770	6,777	6,795	6,805	6780·5
Evaporated per lb. of coal, actual, .	9·36	8·74	8·74	9·35	8·906
Calorimeter open, minutes, ...	45	44	—	25	114
Steam used by calorimeter, lbs., . . .	82	81	—	45·5	208·5
Quality of steam per cent., ...	98·95	98·95	98·95	98·95	98·95
Temperature of water pumped, . . .	34	34	34	34	34
Water pressure in lbs., ...	56·775	56·86	56·96	57·08	56·903
Delivered hd. in ft. (2·307 ft. = 1 lb.), .	130·96	131·25	131·31	131·56	131·275
Distance centre pump to gauge, . .	19·8	19·8	19·8	19·8	19·8
Suction head in feet, ...	10·7	10·594	10·398	11·005	10·77
Total head in feet, ...	161·46	161·644	162·008	162·365	161·845
Millions of foot lbs. per hour, ...	1025·008	1032·6	1032·723	1034·995	1031·520
Actual duty from 100 lbs. dry coal burned, millions foot lbs., ...	150·06	140·08	140·02	150·07	143·30647
Actual duty from 100 lbs. coal burned, millions foot lbs., ...	142·7106	133·238	133·0827	142·7	135·77
Duty from 1,000 lbs. of steam, millions foot lbs., ...	152·45	152·4	152·3	152·5	152·448

THE ADULTERATION OF FOOD.*

BY H. W. WILEY,
Chemist of the U. S. Department of Agriculture.

Barnum made a colossal fortune by acting on the principle that Americans like to be humbugged. There is something soothingly seductive in being led to the circus by lurid posters showing unattainable attitudes of impossible monsters. This attractiveness is increased by the knowledge that, like the limited express, it implies an extra charge. The public would rise with unanimous execration were it to attend a circus where side shows were not known and the *post ludum* concerts were free. Were the feats of legerdemain of the mystic Hermann actual performances of supernatural powers, they would lose for us half their charm. To be cheated, fooled, bamboozled, cajoled, deceived, pettifogged, demagogued, hypnotized, manicured and chiropodized are privileges dear to us all. Woe be to that paternalism in government which shall attempt to deprive us of these inalienable rights. There is no point on which the average American is more sensitive in respect of legal restriction, than in those instances in which the law interposes to prevent him from making a fool of himself. Only after a long struggle has a distinguished citizen of your city, now in public life, been able to prevent the mails from paying the expenses of the delta of the Mississippi. Only the other day, in New Orleans, I read in the lottery advertisement, that the ticket drawing the last capital prize of $75,000 had been sold in Washington, Philadelphia and Kalamazoo. This all doubtless comes from the fact that in this country each one of us is just as good as the next, a condition of affairs, which, in true Gilbertian humor, has been touched off in the distich :

> "When everybody's somebody,
> Nobody's anybody;"

* A lecture delivered before the Franklin Institute.

therefore we should not be surprised at the pertinent inquiry of why A, being no better than B, should interfere with B when B wants to get drunk or buy a lottery ticket.

In regard to the character of what we eat and drink, we find the same unwillingness to be watched over and protected.

A few days ago in Chicago I went out to the Union Stock Yards to look at the process of meat inspection. From each carcass of pork intended for exportation is taken a sample of the flesh and this is carefully examined for trichinæ. "Do you often find diseased samples?" I asked. "Yes," said the attendant, "from one to two per cent. of all the samples examined is found infected." "Could I see a sample of that kind?" "Certainly. Has anyone a trichinosed sample in the microscope?" A pretty girl microscopist held up her hand. I looked and saw for myself the curled and coiled serpent ready for a strike. How I congratulated that lucky sarcophagous Teuton who had been saved from a horrid death by the fairy fingers and sure blue eyes of the trichinæ girl. "What do they do with these infected carcasses?" A shrug of the shoulders led me to believe that they were sent to soap factories as they doubtless are, and this was followed by the expression, "But Americans don't eat raw pork," and I am led to suppose from this that trichinæ are really very good and nice when well broiled. Next morning, when I ordered ham for breakfast, I asked the waiter to have it cut thin and broiled crisp. Even then when it was brought in I could not help thinking that it looked like a bretzel.

That distinguished jurisconsult and patriot, Senator Paddock, of Nebraska, during the first session of the present Congress, after years of futile struggle, succeeded in having the Senate pass what is known as the Pure Food Bill, but it seems from the provisions of this bill that the Congress of the United States has only power to protect the foreigner, the disfranchised and the Indian not taxed. The provisions of the bill are confined to the Territories and the District of Columbia and to interstate commerce. Mild as are the penalties of the bill, allowing the citizens of any

State to make a dessert and call it peas if they like, yet it has been left unpassed in the House of Representatives.

The Paddock Pure Food Bill, to summarize it briefly, has for its purpose the protection of commerce in food products and drugs between the several States, the District of Columbia, the Territories of the United States and foreign countries, and the Secretary of Agriculture is authorized to make the necessary rules for carrying out the objects of the bill. He is authorized to cause to be punished, through the proper courts, any one introducing in any State or Territory, or the District of Columbia or from any foreign country any article of food or drugs which is adulterated or misbranded. The act says that the term "food" shall include all articles used for food or drink by man, whether simple, mixed or compound. In the case of food or drink, an article shall be deemed to be adulterated if any substance or substances has or have been mixed and packed with it so as to reduce or lower or injuriously affect its quality or strength, so that such product when offered for sale shall be calculated to deceive the purchaser; further, if it contain any inferior substance or substances substituted wholly or in part for the article, or if any valuable constituent of the article have been wholly or in part abstracted, or, if it be an imitation of, and sold under the specific name of, another article, or if it be mixed, colored, powdered or stained in a manner whereby any imperfection therein shall be concealed, or if it contain any added poisonous ingredient or any ingredient which may render such article injurious to the health of the person consuming it. Further, the food is declared to be adulterated if it consist of the whole or any part of a diseased, filthy, decomposed or putrid animal or vegetable substance or any portion of an animal unfit for food, provided that an article of food shall not be considered adulterated if it be a mixture or compound sold under its own distinctive name, or an article labelled, branded or tagged so as to plainly indicate that it is a mixture, compound, combination or blend.

It will be seen by the above provisions that the bill is very far-reaching in its character, and it contains also the

proper penalty for enforcing its operation. This bill passed the United States Senate on March 9, 1892. Mr. Paddock, in concluding his speech in advocacy of the bill, used the following words:

"In the name and in the interest of public morality, I appeal to you to set legislative bounds, beyond which the wicked may not go with impunity in this corrupt and corrupting work. Let us at least attempt to perform our part in the general effort to elevate the standard of commercial honesty which has been so disgracefully lowered by these deceptions, frauds and robberies, the malign influence of which is everywhere present, everywhere felt.

"Let us help by our action here to protect and sustain in his honorable vocation the honest producer, manufacturer, merchant and trader, whose business is constantly menaced and often ruined by these unscrupulous competitors, who by their vile and dishonest arts, manipulations and misbrandings are able to make the bad and impure appear to be the pure and the genuine; thus, by a double deception, both as to quality and price, making the worse appear the better choice to the unintelligent mass of purchasers.

"In the interest of the great consuming public, particularly the poor, I beg of you to make an honest, earnest effort to enact this law. At best a great multitude of our people are oppressed by a fear, a never-absent apprehension, which they carry to their work by day, and to their beds by night, that perhaps at the end of the following day, or week, or month, their ends may fail to meet. Under the strain of this grim menace life itself becomes a burden almost too grievous to be borne. But the thought of helpless wife and children, whose sole dependence he is, renews the courage of the wage-worker from day to day, and so he struggles on, praying and hoping to the end.

"These, Mr. President, are the men, and these the women and children, for whom, before all others, I make this appeal. If you could save to these the possible one-third of the nutritious element of their food supplies which is extracted to be replaced by that which is only bulk, only the form and semblance of that of which they are robbed by the dishonest

manipulator and trader, you would go a long way toward solving the great problem of the laboring masses—whether for them it is "better to live or not to live," whether it is better to bear the ills they have, rather than fly to others that they know not of, that lie beyond in the realm of governmental and social upheaval and chaos.

"There is a good deal in the way of comic "asides" as the momentous social drama which holds the boards at this time, and whose *dramatis personæ* are the so-called common people, rapidly advances to the epilogue. Be not deceived! the storm doth not abate. It is ever rising. Its violence is ever increasing. Take heed when the people demand bread that you continue not to give them a stone, lest the angry waves of popular discontent may sometime, perhaps in the near future, rise so high as to overwhelm and engulf forever all that we most greatly value—our free institutions, and all the glories and hopes of our great Republic—which are not ours alone, but which belong—and, if they are preserved and shall permanently endure, will be an ever-continuing blessing—to all mankind."

This Pure Food Bill has received the unanimous support of nearly every agricultural organization in the United States. It has been opposed by a number of manufacturing establishments interested in the production of drugs and mixed foods, and also by those largely interested in the manufacture of substitutes for lard. If adopted it can at once be seen that it would do away with the necessity of the oleomargarine law, which is a special form of legislation and like all special legislation must be open to many objections.

As before stated, the national law, as indicated above, does not protect the citizen of any State against an adulterated food which is manufactured and sold within the State. Such police power must be left wholly to the several States. Many of the States already have laws on their statute books dealing with the subject of food adulteration. These laws, however, are for the most part, inoperative, and, not being based on a common plan, would naturally not secure, even when fully enforced, the same degree of protection in all States. What is needed for a complete legal protection

of the people against adulterated foods is not only the enactment of the Paddock Pure Food Bill but a similar enactment of similar scope and aim for each of the several States.

Among the various States which have laws on the subject may be mentioned Illinois, which has an act to prevent and punish the adulteration of articles of food, drink, and medicine, and the sale thereof when adulterated. There is also a special law preventing the adulteration of butter and cheese.

Iowa has a statute, entitled an act to prevent deception in the manufacture and sale of imitation butter and cheese. One of the provisions of this law is that no keeper of a hotel, boarding-house, restaurant or other public place of entertainment shall knowingly place before any patron, for use as food, any imitation butter or imitation cheese unless the same be accompanied by a placard containing the name in English of such article printed in plain Roman type. Iowa also has a special law in regard to the adulteration of milk.

Maine has a food law to prevent the manufacture and sale of adulterated lard. Maine also has a general law on the adulteration of food and drinks.

Maryland has a statute to provide for the prevention of the adulteration of articles of food and drink and the sale thereof when adulterated or unwholesome. The enforcement of this law is placed largely in the hands of the State Board of Health.

Perhaps the best of the State laws concerning adulteration, are those of Massachusetts, the statutes of which provide "that no person shall within this Commonwealth, manufacture for sale, offer for sale, or sell, any drug or article of food which is adulterated within the meaning of this law." The law of Massachusetts is, in all essential particulars, that of the Paddock Pure Food Bill, of course, with such variations as are necessary in the enactment of a State law as compared with a Federal law. The law of Massachusetts is especially effective as regards the sale of adulterated milk and other adulterated food and has

a system of State inspection which has already reduced the percentage of adulteration of such articles to a very low figure. Monthly returns are made by the inspectors and analysts of foods and drugs. The report for the month of October, which is the latest one, contains the results of the inspection of milk, butter, cheese, olive oil, vinegar, spices, cream of tartar, molasses, maple sugar, maple syrup, honey, tea, coffee, confectionery and miscellaneous articles and drugs. The total number of samples examined was 610; the number found to conform to the legal standard was 428, and the number of samples varying from the legal standard; that is, adulterated within the meaning of the act, 182. The percentage of the adulteration was 29·8. The actual percentage of adulteration is very much less than this, for it is only suspicious articles of food to which the attention of the Board is directed. Certain staple products, such as sugar, flour, and the various cereal products, are very rarely adulterated and receive but little inspection. The work of the Board is, therefore, mainly devoted to the inspection of such articles as have been found, by several years of experience, to be especially liable to adulteration. Eleven actions were brought in the courts during the month for violation of the Food and Drugs Act. Five were for the violation of the statute relating to the sale of milk; two of coffee; one each of honey, cream of tartar, cloves and pepper. In all of the eleven cases conviction followed and fines of $247 in all were imposed. The cities and towns from which samples of food were collected during the month, were Boston, Worcester, Lowell, Cambridge, Springfield, Lawrence, Somerville, Salem, Chelsea, Malden, Newton, Taunton, Waltham, Pittsfield, Brookline, Charlton, Greenfield, Hyde Park, Lee, Marblehead, Milton, Natick, North Adams, Orange, Stoneham, Stoughton and Ware.

The case of Massachusetts is given somewhat at length on account of the excellence of the system of inspection. It shows what a State law can accomplish when wisely made and honestly enforced. In the one item of milk alone, it would be difficult to estimate the amount which has been saved to consumers by the strict enorcement of the law which

requires the milk sold to contain a certain amount of total solids and fat.

Time remains only to mention the other States which have laws of some kind on the subject of adulteration. These States are Michigan, Minnesota (which has a series of good laws, both special and general), New Hampshire, New Jersey (which also has a good system of laws), New York, Ohio (also with a fairly good system), and Pennsylvania, which divides its law into three sections; the first relating to liquors, I suppose because this is the most important of the foods of this State: the second to food adulteration in general and the third especially to dairy products. The weakness of the Pennsylvania law is not so much in the character of the provisions relating to the sale of foods as in the method of securing their enforcement. It does not provide for any system of inspection as does the law of Massachusetts; and no law relating to the adulteration of food is of any value whatever as a protection to the community unless a rigid system of constant inspection is provided for. The Pennsylvania law declares that the addition of water or of ice to milk is an adulteration, and any milk obtained from animals fed on distillery waste is declared to be impure and unwholesome. The removal of the cream is also declared an adulteration. The law prevents the manufacture of any substance provided to take the place of pure butter fat. This is not a restriction on the sale of an adulterated butter, but is a total prohibition of the manufacture and sale of any substitute for butter, even if it be sold under its own proper name.

Continuing the list of States with laws against the adulteration of food, we have next Virginia and Wisconsin. The latter State has a very good law, which not only has a general provision but also enters into detail, especially in regard to dairy products, describing what shall be considered pure milk, or establishing a standard thereof, and stating how an adulteration of milk shall be proved, and how adulterated honey shall be marked. It contains penalties for the sale of unwholesome provisions and items in regard to the adulteration of foods and drugs, fraud in dairy

manufactories, the form of label to be placed on dairy products, the strength of vinegar, etc.

It is hardly patent to this lecture to refer to foreign countries, but it may be said that in general the best laws in this country, national and federal, are based on the English food and drugs act, which is entitled an act to make better provision for the sale of food and drugs in a pure state. This became a law on the 11th of August, 1875.

The laws of the continental countries of Europe are also in the main effective, but contain such a multitude of minutiæ as would render them very burdensome if enacted in this country. The English law has been in operation long enough to prove its efficiency, and under it hundreds of convictions for the sale of impure foods and drugs have been secured.

The Canadian law is essentially the same as that of England, although not so comprehensive.

The States not mentioned in the above list have, so far as could be acertained, no laws relating to the adulteration of foods. At least they were not reported, although inquiries were sent to the Secretary of State of each State in the Union for information in regard to this matter.

Many municipalities also have local laws applying to the sale of adulterated foods. These laws are mostly of a specific nature and apply chiefly to dairy products. There would be no time here to even mention the cities having local laws on this subject, but there are now very few large cities in the country which do not at least have some kind of milk inspection.

Lying at the root of the question of food adulteration is the inquiry, what is meant by pure food? In the laws which have been enumerated, attempts have been made to legally decide what pure food is. Divested of all legal technicality, pure food is a wholesome article of food or drink which is sold and consumed under its proper name. With each particular article there must be established a separate standard which a consensus of experience with a great number of known pure substances in that list shows to be required. For instance, take the case of

milk, which is one of the most common articles of food and perhaps has been more generally adulterated than any other one. Analyses made all over the world on hundreds of thousands of samples of healthy cow's milk, have shown that the average content of solids therein is practically nearly thirteen per cent. A normal milk which falls below this standard shows some peculiarity in the animal giving it, either an incipient disease, deficient nutrition, or some idiosyncrasy. The mixed milk of a herd of healthy animals will rarely fall below this standard. For this reason the standard of twelve and one-half per cent. of total solids in milk has been adopted in most countries having laws on the subject. In some cases the benefit of the doubt is given to the vendor, and a standard is fixed at twelve per cent. Now of these total solids a certain quantity in normal milk must be butter fat. It is not often that the butter fat of a perfectly healthy cow's milk falls below three per cent of the total weight of the milk. It is much more apt to be three and one-half per cent.; hence, in fixing a standard of pure milk not only must the percentage of solids be given, namely, twelve or twelve and one-half per cent., as the case may be, but also the quantity of fat contained therein. This percentage varies in different laws from two and three-fourths to three and one-half per cent.

In a similar method the standard of purity of any other article of food must be determined by a careful examination of pure samples from all quarters and by then fixing a standard below which an article must be regarded as suspicious or adulterated.

As a distinction between a pure and an adulterated article take the cases of butter and oleomargarine. Pure butter, for instance, must be clean, sweet, wholesome and made of the fat of cow's milk and must contain only a certain proportion of water, curd and salt. Oleomargarine may be as sweet, clean and wholesome as the butter mentioned above, yet when sold as butter it is clearly not pure food, but a a spurious article.

Again, when the housewife buys lard it is supposed that

the article she obtains has been made from the fat of healthy, freshly slaughtered hogs, carefully selected and cleaned and rendered in clean kettles or tanks. Cotton-seed oil and beef tallow, in respect of cleanliness, nutritive properties and wholesomeness may equal and even excel pure lard, but the admixture of these articles with hog's lard, or their sale as such without the knowledge of consumers, is clearly a fraud and an adulteration.

From a practical point of view, food adulteration may be considered under two general aspects, namely:

(1) Adulteration harmless to health and practised merely for cheapening the article or making it more attractive to the sight or taste.

(2) The addition to a food or drink of substances positively injurious to health.

Such substances are added chiefly as preservatives or for the purpose of coloring or decolorizing, or for the purpose of giving a particular flavor or taste. As a rule, they are added in minute quantities. In fact, the proportion of such substances is usually so small that a moderate or intermittent use of food so treated may not produce any great injury to the system. The continued use of such articles, however, must end in the impairment of the general health and sometimes in permanent injury.

In the latter class of adulterations must also be included those injurious substances naturally arising from the decay of wholesome foods, or from the development of noxious substances in canned foods, or from the formation of poisonous salts by the action of the canned foods on the solder and tin of cans. Such materials, while not intentionally added, are, nevertheless, adulterations within the true scope and meaning of the term as applied to foods. In other words, it is not necessary to prove intent in order to establish the fact of adulteration. Any food which is not what it purports to be, which contains any unwholesome or poisonous ingredient, or which has any artificial coloring or facing material, is, to all intents and purposes, adulterated.

There is one legal exception to the above classification, namely, the use of annatto in coloring butter. The national

oleomargarine law, applied to the Territories, the District of Columbia and to interstate commerce, permits an artificially colored butter to be passed as genuine, and I believe most State laws referring to this subject contain the same provision. Indeed, in some States oleomargarine exposed for sale is required by law to be stained pink or some other color distinctive from yellow, and such a stain, while an actual adulteration, could not be classed as illegal.

There is still another form of fraud in food which may be defined as a negative adulteration. It consists in extracting from a food part of some valuable ingredient, and selling the residue as the genuine article. The sale of skimmed milk for whole milk, and of spent tea leaves for genuine leaves are illustrations of this kind of fraud. Perhaps the best method of illustrating these various kinds of fraud and adulteration will be to call attention to some of the articles sophisticated in the ways described. No attempt, however, will be made to give a complete list of adulterated articles, for such a list would fill a volume. Attention, therefore, will be called only to the more important articles of food, and to those which are most commonly adulterated. In addition to this, examples will be given of some peculiar forms of adulteration which are little known to the public.

Milk.—Normal cow's milk should contain about three and one-half per cent. of butter fat, and should yield, on standing in a cool place for twenty-four hours, from ten to twenty per cent. by volume of cream. Until the establishment of milk inspection in cities, whole milk was something of a rarity. With careful inspection, such as obtains in Boston, the percentage of adulteration has been largely reduced.

An ingenious method of milk adulteration is sometimes practised by the shrewd husbandman in such a way as to preserve his tender conscience from being seared. The cream in the cow's udder is naturally separated in part from the milk, unless the cow, just previous to milking, be subjected to violent exercise. The first milking, therefore, is less rich in butter fat, and it can be sent directly to the consumer. The last of the milking, called strippings, on the other hand, is nearly pure cream, and can be preserved

for butter-making. Butter fat, being lighter than whole milk, cannot be removed without increasing the density of the remainder above the normal. This density, however, can be reduced to the proper limit by the judicious addition of water. The testing of milk by the lactometer alone is therefore not a certain method of discriminating between a pure and an adulterated article.

Condensed milk is made by evaporating whole milk at a low temperature and in a high vacuum, in copper vessels, yet even at this low temperature some of the distinctive aroma of the milk is carried off by the escaping vapors. It therefore happens that even when evaporated milk is diluted to its original volume with water, it is never exactly itself again. Yet a pure condensed milk is not an adulterated article, for it is sold as condensed milk, and hence no fraud is practiced. When, on the contrary, as is often the case, sugar or salicylic acid is added in order more securely to preserve the condensed product, then a perfect case of adulteration is established. The manufacturer, however, may relieve himself of all responsibility, in so far as the addition of sugar is concerned, by stating on the label the amount added. In cases of deleterious preservatives, however, there would be no excuse. Their use in all cases should be prohibited.

Butter.—In regard to butter, the character of adulteration is well known. The use of oleomargarine as a butter substitute has been practiced for many years. The oleomargarine law, which imposes a tax of two cents a pound on the manufactured product, has not helped to restrict its use, but has rather increased it by giving to the consumer a guarantee of purity. The amount of tax collected on manufactured oleomargarine for the fiscal year ending June 30, 1892, was $945,675, which shows that there were 47,283,-750 pounds of oleomargarine manufactured in the United States in twelve months.

The number of retail dealers in oleomargarine increased during the year more than twenty-five per cent. over the preceding year. The amount of tax paid by retail dealers for the fiscal year ending June 30, 1891, was $146,293.70, and for the fiscal year ending June 30, 1892, $204,215.

The increase in the number of wholesale dealers was nearly 100 per cent. The amount of tax paid by wholesale dealers for the fiscal year ending June 30, 1891, was $53,191, and for the fiscal year ending June 30, 1892, $106,036.

There can be no reasonable objection to the use of oleomargarine; it is clean, wholesome and digestible. When it is to be kept for a long time before use, as on ship board or in distant mining camps, it is preferable to butter, because it has but little tendency to become rancid.

Lard.—For similar reasons there can be no possible objection to the use of cotton-seed oil as a substitute for lard or when mixed with lard, provided it be sold for what it is. Most of you are familiar with the great fight which was made against the use of the term "pure refined lard," which was the trade name of a mixture of lard stearine with cotton-seed oil. "Pure refined lard," it was claimed, was a term which had been used so long to designate the mixed product that it had become in reality a trade-mark, and was therefore entitled to respect and protection. In the investigation which was held before the Congressional committees, it appeared that as to the trade the contention was quite justifiable. Goods sold under that name were understood to be mixed. When, however, the mixed product was offered to the consumer, it was purchased with the idea which the name naturally implied, that an extra fine quality of hog's lard was secured.

All attempts to pass a pure lard bill, modelled on the Oleomargarine Act, have heretofore failed in Congress, but several of the States have prohibited the sale of mixed lard, except when offered under the proper name. Manufacturers have, therefore, been gradually forced to abandon the term "refined lard" when applied to this commodity.

I am of the opinion that many persons would prefer a cooking fat largely of vegetable origin to a pure animal product. To me it seems that some State Legislatures have taken a reprehensible course in prohibiting the sale of vegetable oils as a substitute for lard for cooking. The grower of hogs undoubtedly has a right to contend against the sale of vegetable oils as hog fat, but when he

pushes his claim still further and demands that the markets be closed to products as pure and nutritious as his own, he passes beyond the bounds of public support. Every person in the United States who prefers cotton oil to lard should be allowed to purchase his supplies without let or hindrance. Every grower and maker of pure lard has the right to an equally open market, from which every adulterated and mixed lard, offered as pure, should be rigidly excluded.

For a time, a few years ago, when a popular fad prevailed in favor of nitrogenous foods, the true value of fats to the digestive and nutritive economy was not well appreciated. At the present day this is all changed, and we know how to value a fat properly.

It is therefore a matter of no mean importance to protect the public in the use of olive oil instead of cotton oil, of cotton oil instead of lard, and lard instead of a mixture of beef and cotton oil stearine. It is true that cotton oil, when carefully refined, is almost as good a salad dressing as olive oil, but it is very much cheaper, and those who prefer to pay the high price should be secured against fraud. In respect of wholesomeness and digestibility it would be hard to choose wisely between the two.

One of the great difficulties in securing the enactment of a National Pure Food Bill has been the feeling in cotton-growing regions that such a bill would restrict the market for cotton oil. This is true if the fraudulent market is meant. By that I mean the surreptitious sale of cotton oil as olive oil and as lard. But such a bill would not interfere in the least with the legitimate market for this product. Cotton oil, as a food, has such merit of its own as to warrant the belief that it does not require any smuggling to secure for it a wide and rapidly increasing use. The South as well as the North would be the gainer from honest markets for honest foods, and it is a short-sighted policy that leads to a crusade against such legislation as will secure the desired result. It would be a rather unfortunate thing for the whole country should an irrepressible conflict between the *sus* and the *gossipyum* keep our interstate market forever open to mixed or doubtful fats.

Sugar.—The common idea that the grocer puts sand in his sugar is not borne out by the facts in this country. I doubt whether a single pound of white sand has been put into the sugar supply of this country in the last ten years. It is one of those popular fallacies which gain credence inversely proportional to their truth. The granulated and white lump sugars which are found in our markets are almost absolutely pure; as pure indeed as the utmost care in manufacture can make them. Occasionally a little flour or starch may find its way into the powdered sugar, but such instances must be exceedingly rare. Low-grade sugars contain molasses and water as a result of the way in which they are made and dried. In the refineries, after the pure white sugar has been secured, the molasses therefrom is reboiled and a second crop of sugar crystals obtained. These form the so-called coffee sugars of commerce. In a like manner a third crop of rather light colored crystals may often be formed. By a combination of low temperature and high vacuum in boiling, and by a manipulation producing small crystals, a sugar can be made very soft, and, so prepared, it absorbs a good deal of the mother liquor in which its crystals grow. It is possible, in this way, to put on the market a fairly light-colored and attractive sugar, which may not contain more than eighty-five per cent. of pure sugar. This process of making low-grade sugars is practiced chiefly with the product of the sugar cane. In sugar from beets the molasses and mother liquors are usually so highly charged with alkaline salts as to render the manufacture of low-grade sugars, fit for table use, a very difficult matter. In this country, as is well known, the greater part of the sugar consumed is made from sugar cane. Of the 4,000,000,000 pounds which we have eaten in the last twelve months, probably 3,500,000,000 have been grown under tropical suns. The proportion of yellow, coffee and low-grade sugars offered is therefore, greater in our markets than in Europe, where the sugar beet supplies nearly all of the sugar consumed.

Syrups.—In respect of molasses and syrups the bill of health is not quite so clean. The quantity of pure maple syrup

sold annually is well calculated to make the maple forests of Vermont prick up their ears. A very little maple molasses mapleizes the whole jugful; a fact that makers and sellers have not been slow to learn. An extract of hickory bark imparts a misleading flavor to a syrup made from cane sugar and starch, and a patent has been granted by the United States protecting the discoverer of this process in the exercise of his invention. Judicious mixtures of glucose, sugar, syrup and maple flavor are the secrets of the marvellous expansiveness of maple molasses between the tree and the gullet.

"Golden drips," "honey syrups," etc., are names given to compounds made of refinery refuse, glucose and centrifugal cane molasses. The great base of all our table syrups is glucose made from corn starch. I am far from denouncing glucose as a dangerous ingredient in such mixtures. On the contrary, when glucose is properly made, it is both palatable and wholesome, but its sale as maple molasses or as refiner's syrup or as open kettle molasses is clearly fraudulent.

Honey.—Liquid honey is very largely adulterated with glucose. Of 500 samples of honey bought in fifteen large cities and examined by the Chemical Division of the United States Department of Agriculture, nearly forty-five per cent. were found to be fraudulent. Of comb honey, only that is adulterated which comes in bottles or jars. A few years ago, there was a popular impression, which I shared, to the effect that comb honey in the frame was adulterated, but no sample of this kind has ever come under my observation, and I am convinced that such a species of adulteration does not exist. Perhaps there is no class of food producers in the country whose business has been so seriously injured by adulteration as the bee growers. Many of them, however, do not seem to realize the magnitude of the frauds which are perpetrated against them. They have often been known to denounce, as attempts to injure their business, the statements that such frauds are practiced. Of late, since indubitable evidence of fraud has been presented to them, they have determined to use every means to end it.

Coffee.—Almost equally subject to adulteration is ground coffee. The high price of coffee is a special incentive to sophistication. In former days it was largely the custom to buy the green berry, and each consumer would do his own roasting. Now it is fashionable not only to buy the roasted berry but also to buy it in a ground state. Chicory, roasted peas, beans, etc., are often found in large proportions in such preparations, and in fact it is somewhat rare to find a pure ground coffee. It might be held that such sophistication would end with the ground article, but such is not the case. The berries themselves have been imitated both in the green and in the roasted state. The moistened mass of chicory, starch, pea meal, caramel, molasses, etc., is moulded into the proper shape, and, when dried, these imitations might easily escape detection when mixed with the genuine berries. Those who are so fortunately situated as to be permitted to live at home and regale themselves each morning with an aromatic cup of Mocha or Java, scarcely realize what it means to drink a lukewarm concoction of chicory and pea meal, bluish black in color, but decidedly yellow in flavor.

Tea.—Thanks to our customs laws very little tea is found in this country adulterated with foreign leaves. The chief adulterations practised with tea are found in the use of spent leaves and in the practice of facing. The practice of facing consists in treating the leaves with some preparation designed either to increase their weight or to improve their appearance. Salts of iron and copper are often used for this purpose. Some of these facing materials are quite prejudicial to health, and such teas are best excluded from the breakfast table.

Cocoa.—Cocoa and chocolate are largely adulterated with starch and sugar, harmless in themselves, but far cheaper than the meat of the *cocoa theobroma.* The natural oil of the cocoa bean is also often extracted, and its place supplied by a cheaper fat or left without an oil. These various preparations are offered under fancy names and with wonderful claims of excellence. But in general we may say that the

food value of a preparation is not much improved by having it digested before it is eaten. Yet often we see it claimed for a given mixture that it has had all of its difficultly digested components removed and that these are replaced by others with which the gastric juice can have a veritable pic-nic. The digestible cocoas often belong to this class, and, perchance, may have little of the virtues of the original beans left in them.

Canned Foods.—Of canned foods I should like to say something, but it is difficult to select the little which can yet be said. First of all, the material of which the cans are composed is a matter to deserve attention. It is undoubtedly true that glass is the ideal substance for cans designed to preserve food products. But the first cost of these packages and the danger of breakage during filling and transportation, exclude them from competition with tin in all except the choicest brands of preserved foods. Fortunately, tin is a metal which is not only troublesome to the tariff but also resistent to most organic acids. It is acted on very slowly or not at all by most organic acids found in fruits, vegetables and meats. In some countries, such as Germany, the tin which is used in contact with canned foods is required to be almost pure, and to contain not more than one or two per cent. of lead. The most abundant adulterant of tin, as found in tin cans, is lead, and it is against the presence of lead that it is especially necessary to guard, inasmuch as the organic salts of lead, without exception, are poisonous. In this country of personal liberty there is no restriction as to the percentage of lead which tins used for canned foods may contain. We have found as high as twelve per cent. of lead in tin from cans which have contained food designed for consumption. Such a high percentage of this dangerous metal cannot fail to excite alarm. We have also found numerous evidences of erosion on the tinned surfaces exposed to the action of the contents of the can. The contact of the preserved goods with solder should also be carefully prevented, inasmuch as solder contains often as much as fifty per cent. of lead. It is very common, however, to

find lumps of solder in the canned goods and also to find the solder protruding through the points of union of the can and cover so as to be exposed to the action of the contents.

Copper in Peas.—Equally objectionable is the habit of using copper salts to impart a bright green color to canned peas and other goods. The imported French peas are uniformly colored with copper. The addition of a little copper, in any vegetable which it is desired to keep green when served, has a happy effect in that direction, and fashionable cooks have not been slow to learn this. It is true that the quantity of copper which one would eat in a single meal where French peas are served, would not prove greatly injurious, but on that large part of our population who are compelled to dine every day on truffles and peas interspersed with terrapin and champagne, there is great danger of the copper acting with accumulative effect.

I have already spoken of the danger which may lurk in preservatives, such as salicylic acid, but there is also an occasional source of danger in the development of nitrogenous bodies called ptomaines in preserved meats. These bodies may develop with astounding rapidity if a can of meat be opened, and not eaten for a day or two. An illustration of the fatality of the action of such bodies is unfortunately often found in the case of tyroxicon, a poison often developed in milk or cream.

The above will serve as illustrations of the more common forms of adulteration to which our foods are subjected. The idea might be formed from this array of facts that foods are almost all adulterated, and that it is extremely difficult to obtain anything pure. Newspapers love to magnify these accounts of adulteration. What I have placed before you has not been for the purpose of exciting a panic on the subject of foods. Much the greater part of foods which Americans eat is pure and wholesome. It is only the small quantity of adulterated food from which we should strive to protect ourselves. This exaggeration of the adulteration of food has been humorously portrayed by Burdette in a little scrap of rhyme, entitled

A VICTIM OF DELUSION.

Placid I am, content, serene.
 I take my slab of gypsum bread,
And chunks of oleomargarine
 Upon its tasteless sides I spread.

The egg I eat was never laid
 By any cackling, feathered hen ;
But from the Lord knows what 'tis made
 In Newark by unfeathered men.

I wash my simple breakfast down
 With fragrant chickory so cheap ;
Or with the best black tea in town—
 Dried willow leaves—I calmly sleep.

But if from man's vile arts I flee
And drink pure water from the pump,
I gulp down infusoriæ,
And hideous rotatoriæ,
And wriggling polygastricæ,
And slimy diatomaceæ,
And hard-shelled orphryocercinæ,
And double-barrelled kolpodæ,
Non-loricated ambrœilæ,
And various animalculæ,
Of middle, high and low degree ;
For nature just beats all creation
In multiplied adulteration.

Even the conservative work of the Department of Agriculture in investigations of food adulteration, which I have had the honor to conduct during the past six years, becomes most highly sensational material when portrayed in the columns of the daily journal. In the *Philadelphia Star*, of recent date, appeared the following remarkable statement of the work of the Chemical Division :

"Glucose, it appears, is the greatest of all adulterants. It is used for making cheap candy, sugars, jellies and syrups. Apple sauce is pumpkin boiled in cider. It is said that the cheap confectionery and liquors are the articles most injuriously adulterated. Candy commonly contains much fusel oil and other poisons. Strawberry ice cream – a plate of it—often contains almost more fusel oil than five glasses of poor whiskey. It is colored with red aniline dye.

Licorice drops are usually made out of candy factory sweepings. Wine is frequently nothing but water with a percentage of crude alcohol from grain or the refuse of beet refineries, colored with burnt sugar, flavored with oil of cognac and given an agreeable woody taste with a little catechu. When one buys tea for $1 a pound, one is very likely to pay in reality $2 a pound because one-half the quantity is currant leaves. Grated horseradish is sometimes composed of turnip. Flour is frequently weighted with soapstone. Sweetened water, sharpened with citric and tartaric acids and flavored with the oil of orange skin, makes orange cider. Real honey can be distinguished, under the microscope, by the pollen grains it contains. They have wonderfully beautiful forms and the very flowers from which the honey was obtained can be identified by the various exquisite shapes of these fructifying germs."

The above startling facts in regard to adulteration, which are attributed to the Department of Agriculture, are worthy of especial notice because not one of them was ever abstracted from any report of the Department. Scarcely a single instance of the adulterations mentioned above has ever been observed and reported on by the chemists of the Department. Thus it is seen that the popular idea of adulteration is really very much at fault and this has been due largely to the exaggerated statements of presumably honest men who desire to call attention to the fraud and to prevent it by exciting the popular mind against it. The adulteration of our foods and drugs is certainly bad enough, but in my mind it does no good whatever to exaggerate, falsify and misstate the results of careful and unbiased investigations. As has before been intimated, in this address, the remedy against all these things lies clearly in the power of the people. Wise laws wisely administered, a careful system of inspection, a demand for pure food, will secure the people in their right. It is not the rich for whom we should work, but the poor, and they should be protected against frauds in food; frauds not so dangerous on account of being deleterious to health as because of their pretensions to furnish to the poorer part of our people a food

ostensibly pure and nutritious but in reality valueless. It is not supposed for a moment that any system of legislation can entirely prevent the perpetration of frauds upon the community, but at least these crimes can be made punishable and their perpetrators may be compelled to endure the penalty of their misdeeds.

NOTES ON THE DESIGN OF GEAR WHEELS.*

By Prof. L. F. Rondinella.

Toothed or gear wheels are used in machinery to transmit power from one shaft to another near it. The most important classes are: (*a*) spur wheels, (*b*) bevel wheels, (*c*) worm wheels, (*d*) lantern wheels, (*e*) Crown wheels and (*f*) cog wheels.

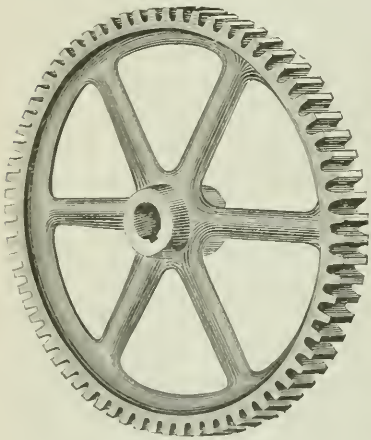

Fig. 1.

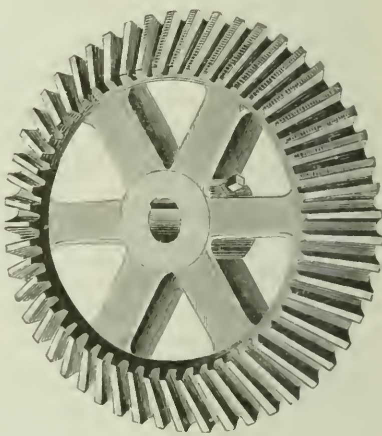

Fig. 2.

(*a*) A *spur wheel* (*Fig. 1*) is one in which the teeth extend radially outward from the rim, in the plane of the wheel. Two spur wheels are used to transmit power between parallel shafts.

* Revised and augmented from lecture notes prepared originally for students of the Philadelphia Manual Training School.

(*b*) A *bevel wheel* (*Fig. 2*) is one in which the teeth extend outward perpendicularly from a rim making an oblique angle with the plane of the wheel, like the frustum of a cone. Two bevel wheels are used to transmit power between non-parallel shafts.

Mitre wheels (*Fig. 3*) are bevel wheels in which the teeth are at 45° to the face of the wheel and are used to transmit power between *perpendicular* shafts.

(*c*) A *worm wheel* (*Fig. 4*) has its teeth cut slantingly across the rim of the wheel, to gear with an endless screw or *worm*. This combination is used to transmit power between shafts

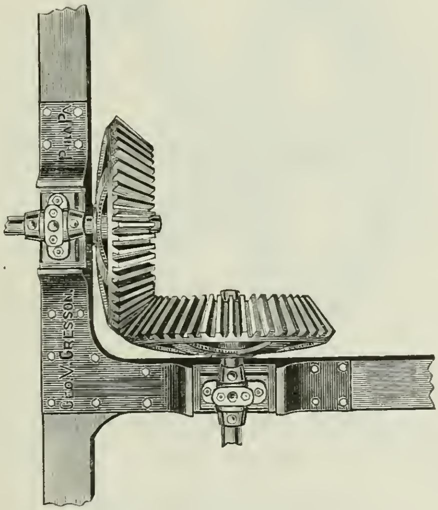

FIG 3.

running at very different speeds, and with their axes in different planes.

(*d*) A *lantern wheel* is one in which the teeth consist of rods connecting two circular discs or faces. It is most used in clock-work, geared with an ordinary spur wheel.

(*e*) A *crown wheel* is one in which the teeth extend at right angles from the side or face of the wheel, and is used in rough gearing between perpendicular shafts.

(*f*) A *cog wheel* is any kind of gear wheel in which the teeth are made separate (generally of wood), and inserted in mortises in the rim of the wheel.

An *internal gear* or *annular wheel* is one in which the teeth are on the *inside* instead of on the outside of the rim.

In a pair of gear wheels, the wheel which imparts the power is called the *driver*; that to which power is imparted is called the *driven wheel* or *follower*. A small gear wheel is called a *pinion*. A *rack* is a straight bar with teeth extending outward perpendicularly from its edge. It moves,

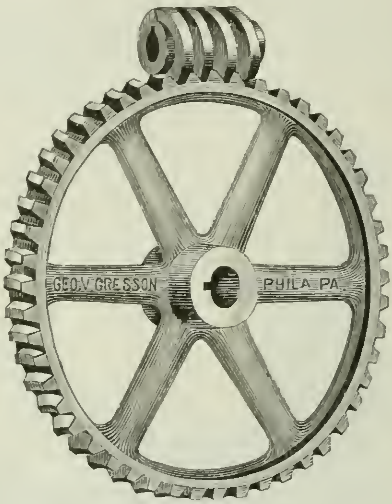

Fig. 4.

therefore, in a straight line (a circle of infinite radius), and is usually geared with a spur wheel. (See *Fig. 5* or *6*.)

TEETH OF GEAR WHEELS.

The circle in gear wheels which corresponds to the circumference of solids of revolution rolling one upon another is called the *pitch circle*. This is the line of reference in designing all toothed gears, its diameter being used to designate the size of the wheel, and the proportions for the teeth and spaces being laid off upon or at right angles to it. Good proportions for the teeth of *cast-iron gears* are as follows (*Figs. 5* and *6*):

$a\ b$ = part of the pitch circle.

$c\ c$ = circular pitch = p.

$c\ d'$ = thickness of tooth = $\frac{15}{32}p$ or $0{\cdot}47\ p$.

$d\,e$ = width of space = $\frac{17}{32}\,p$ or $0{\cdot}53\,p$.

f = height of face (above pitch circle) = $\frac{11}{32}\,p$ or $0{\cdot}34\,p$.

g = depth of flank (below pitch circle) = $\frac{13}{32}\,p$ or $0{\cdot}41\,p$.

$g + f$ = total height of tooth = $\frac{3}{4}\,p$ or $0{\cdot}75\,p$.

$g - f$ = clearance = $\frac{1}{16}\,p$ or $0{\cdot}07\,p$.

Thickness of rim = $0{\cdot}50\,p$.

Perpendicular breadth of face = $2{\cdot}50\,p$.

Other proportions as in belt pulleys.

In dimensioning bevel gears the sizes should always refer to the larger face.

CIRCULAR AND DIAMETRAL PITCH.

These different proportions of the tooth are all expressed above in terms of the absolute or *Circular Pitch*, which is *the distance on the pitch line between corresponding points of consecutive teeth.* This absolute pitch is technically called *circular* pitch to distinguish it from the relative or *Diametral Pitch* by which the number of teeth is expressed in terms of the pitch diameter; as, *e. g.*, a diametral pitch of "$\frac{1}{10}$ inch" or "10 per inch," or simply "10 pitch" means that for each inch in the diameter of the pitch circle there are ten teeth on the circumference of the wheel. The great convenience of this system lies in the fact that the number of teeth can be found at once if the diameter is given—or the diameter can be found if the number of teeth is given—from the equation,

$$\textit{No. of teeth} = \textit{Diametral pitch} \times \textit{diameter},$$

the diametral pitch being taken as expressed in the last two forms above.

The circular pitch may be found as the circumference of a circle is found from its diameter, *i. e.*, by multiplying the diametral pitch in inches by $3{\cdot}1416$.

TOOTH CURVES.

The curves used in shaping the teeth of gear wheels are the *cycloid, epicycloid* and *hypocycloid*, and the *involute*.

A *Cycloid* is the curve generated by a point in the circumference of a circle rolling along a straight line. It is used for the faces and flanks of teeth in a rack.

An *Epicycloid* is the curve generated by a point in the circumference of a circle rolling on the *outside* of another circle. It is used for the faces of teeth in a wheel.

An *Hypocycloid* is the curve generated by a point in the circumference of a circle rolling on the *inside* of another circle. It is used for the flanks of teeth in a wheel.

To form the curves for cycloidal teeth the circumference of the describing circle to roll on the pitch line should be equal to $6\,p$; or its diameter should equal

$$\frac{6\,p}{3{\cdot}1416} = 1{\cdot}9\,p.$$

When the circumference of the pitch circle $= 12\,p.$, viz: in a wheel with 12 teeth, the hypocycloids for the flanks of the teeth will become straight, radial lines.

An *Involute* is the curve generated by a point in a straight line moving tangentially around a circle, *e. g.*, the end of a cord held taut and wound around a cylinder. It is used with a radial line in forming the profiles of teeth in a wheel.

PROPORTIONING GEAR TRAINS.

A *train* of gearing consists of two or more gear wheels meshing together, usually to change the speed at which power is transmitted from one shaft to another. The speed (number of revolutions per minute) of the wheels varies inversely as their pitch diameters, their circumferences, or their numbers of teeth—the latter being necessarily of the same pitch in both wheels. These values can be calculated from one another by substitution in the proper members of the following equation:

$$\frac{\text{Speed of Driver }(d)}{\text{Speed of Follower }(f)} = \frac{\text{Pitch Diam. of }f}{\text{Pitch Diam. of }d} =$$

$$= \frac{\text{Circum. of }f}{\text{Circum. of }d} = \frac{p}{p} \times \frac{\text{no. of teeth in }f}{\text{no. of teeth in }d}$$

The *distance between shaft centres* equals half the sum of the two pitch diameters.

The number of cycloidal teeth in the pinion or smaller wheel should not be less than twelve, and with involute

teeth it should not be less than sixteen. Circular pitch for cast gears should be limited between one-half and five inches.

In a wheel of good cast iron, where the breadth of face equals 2·5 p, the number of teeth (t) necessary to safely transmit any horse-power (P) at a given number of revolutions per minute (r) may be found from the equation

$$t = 800 \frac{P}{p^3 r}$$

ODONTOGRAPH TABLES FOR CAST GEARS.

TO DRAW CYCLOIDAL TEETH.

Table 1.—Find the given *number of teeth* for the wheel in either outside column, and opposite, in the column headed

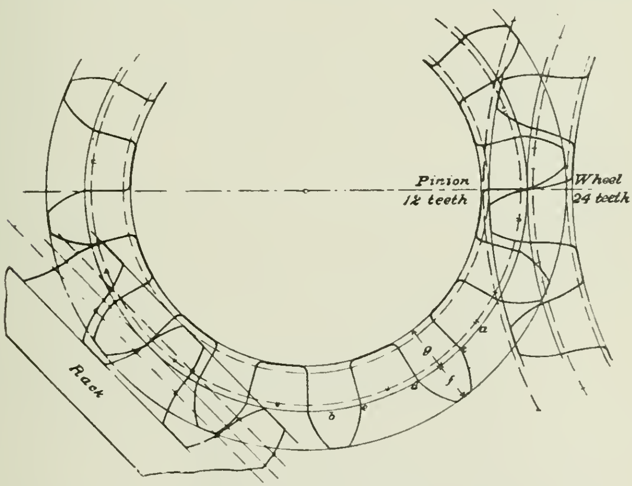

FIG. 5—Cycloidal teeth.

by the given circular pitch, find the diameter of the pitch circle. Lay this off on a centre line, and through its extremities, from the centre point draw the pitch circle. Divide it into as many equal spaces as there are to be teeth in the wheel, and the length of each *arc* should exactly equal the given circular pitch. (The length of the chord is of course less). At the bottom of the same column in the table, find the *thickness* of the tooth, and lay it off around the

pitch circle on the same side of each pitch point. The part of the pitch remaining will be the proper width of space. In the same column of the table find the *height of face* and *depth of flank*, and lay them off on the centre line, the former outside and the latter inside of the pitch circle. Through these two points, from the wheel centre, draw circles which will determine the points and roots of all the teeth. Then in

Table 2,—find the given number of *teeth* in either outside column, and opposite, under the proper *pitch*, in the column headed *Fa.* find the radius of the circle for centres of *face* curves, and in the column *Fl.* the radius of the circle for centres of *flank* curves. With these radii draw those circles from the wheel centre. (There is no *Fl.* radius for twelve teeth, as the flanks are straight, radial lines.) Then in

Table 3,—opposite the proper number of *Teeth*, and under the proper *Pitch* in the column headed *Fa.* find the radius for *face* curves. Set the compasses to this distance, place one foot at the side of a tooth on the pitch circle and the other across that tooth on the inner circle of centres, which will give the centre for that face curve. With this centre and the same radius draw the curve from the pitch circle to the circle that determines the tooth points. Draw all the other face curves in the same way. Then in the column headed *Fl.* find the radius for *flank* curves. Set the compasses to this distance, place one foot at the side of a tooth on the pitch circle, and the other away from (not across) that tooth on the outer circle of centres, which will give the centre for that flank curve. With this centre and the same radius draw the curve from the pitch circle to the root circle, and then draw all the other flank curves in the same way. Fillet the corners to a radius equal to the *clearance* obtained from *Table 1*.

In drawing a rack, the pitch line, the limiting lines for the teeth, and the lines of centres are all straight; the height of face and the *plus* distance for the line of flank centres are measured outward from the pitch line, and the depth of flank and the *minus* distance for the line of face centres are measured inward from it. The centres are then laid off, and the curves drawn as in a wheel.

TO DRAW INVOLUTE TEETH.

Draw the pitch circle; lay off on it the widths of teeth and spaces, and draw the limiting circles for points and roots as described for cycloidal teeth in first paragraph above. Then in

Table 4,—find the given number of *teeth* in either outside column, and opposite, under the proper *Pitch*, in the column headed *Cen.*, find the radius for the circle of centres, and

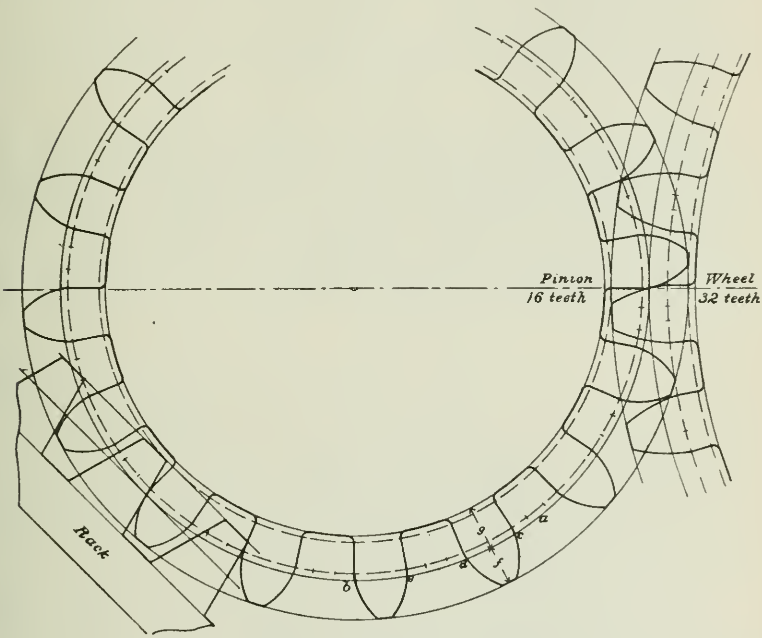

FIG. 6—Involute teeth.

then draw that circle concentric with the pitch circle. In the column headed *Cur.* find the radius for the tooth curves. Set the compasses to this distance, place one foot at the side of a tooth on the pitch circle and the other across that tooth on the circle of centres, which will give the centre for that face curve. With this centre and the same radius draw the curve from the circle of centres to the limiting circle for tooth points. Draw all the other tooth curves in the same way, and finish the flanks by straight, radial lines with the

corners filleted to a radius equal to the *clearance* obtained from *Table 1*.

In the rack to gear with involute teeth the sides of its teeth are straight lines drawn at 75° to the pitch line as described under involute teeth. See *Case I*, below.

The values in the tables are obtained by the methods of using circular arcs for cycloidal and involute tooth-profiles, as described below. These are modifications by the writer of the constructions of Willis and Reuleaux, and will be found to approximate very closely indeed to the true curves.

TO DRAW CYCLOIDAL TEETH APPROXIMATELY BY CIRCULAR ARCS.

Case I: The Rack.—Draw the pitch line and mark on it the pitch points—the widths of teeth and spaces alternately. Draw limiting lines for the total height of the teeth, parallel to the pitch line. Through the *middle* point of a pitch, draw a line crossing the nearest tooth *outside* of the pitch line and inclined 15° to it, and mark off on that line ·5 p on each side of the intersection. Those points will be the centres for the face and the flank curves, the radius being the distance from each centre to the pitch point *beyond* the intersection. Through these two centres draw lines parallel to the pitch line. The outer line will be *the line of centres for flanks* and the inner one *the line of centres for faces.* With centres on these lines, and the respective radii found above, draw all tooth curves.

Case II: The Wheel.—Draw the pitch circle and mark on it the pitch points. Draw limiting lines for the total height of the teeth, concentric with the pitch circle. Through the *middle* point of a pitch draw a radius and also a line inclined 75° to it, crossing the nearest tooth *outside* the pitch line and a line perpendicular to this or inclined 15° to the radius. Mark points on the last line 1·84 p (approximately $1\frac{7}{8}$ p) on both sides of the intersection, and through those points and the wheel centre draw straight lines until they cross the 75° line. The points thus found on the 75° line will be the centres, and the distances from them to the pitch points beyond the intersec-

(*Rondinella.*)

LE III.—RADII FOR TOOTH CURVES.

1½"		1¾"		2"		2¼"		2½"		2¾"		3"		←Pitch
Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Teeth
1 3/32	—	1 9/32	—	1 15/32	—	1 21/32	—	1 27/32	—	2 1/32	—	2 7/32	—	12
1 1/8	10 3/8	1 5/16	12 1/8	1 1/2	13 7/8	1 11/16	15 5/8	1 7/8	17 5/16	2 1/16	19 1/16	2 1/4	20 13/16	13
1 1/8	5 13/16	1 5/16	6 25/32	1 1/2	7 3/4	1 11/16	8 23/32	1 7/8	9 11/16	2 1/16	10 21/32	2 1/4	11 5/8	14
1 1/8	4 13/32	1 5/16	5 1/8	1 17/32	5 7/8	1 23/32	6 19/32	1 29/32	7 5/16	2 3/32	8 1/16	2 9/32	8 13/16	15
1 1/8	3 21/32	1 5/16	4 1/4	1 17/32	4 7/8	1 23/32	5 1/2	1 29/32	6 3/32	2 3/32	6 23/32	2 9/32	7 5/16	16
1 5/32	3 3/16	1 11/32	3 23/32	1 9/16	4 1/4	1 3/4	4 25/32	1 15/16	5 5/16	2 1/8	5 27/32	2 11/32	6 3/8	17
1 5/32	2 29/32	1 11/32	3 3/8	1 9/16	3 7/8	1 3/4	4 3/8	1 15/16	4 27/32	2 1/8	5 5/16	2 11/32	5 13/16	18
1 3/16	2 23/32	1 3/8	3 3/16	1 19/32	3 5/8	1 13/16	4 3/32	2	4 17/32	2 3/16	4 31/32	2 13/32	5 7/16	19
1 3/16	2 9/16	1 3/8	3	1 19/32	3 7/16	1 13/16	3 7/8	2	4 5/16	2 3/16	4 23/32	2 13/32	5 5/32	20
1 7/32	2 11/32	1 13/32	2 3/4	1 5/8	3 1/8	1 13/16	3 1/2	2 1/32	3 29/32	2 1/4	4 9/32	2 7/16	4 11/16	22
1 7/32	2 3/16	1 13/32	2 9/16	1 5/8	2 15/16	1 13/16	3 5/16	2 1/32	3 11/16	2 1/4	4 1/32	2 7/16	4 13/32	24
1 1/4	2 3/32	1 7/16	2 15/32	1 21/32	2 13/16	1 7/8	3 5/32	2 1/16	3 1/2	2 9/32	3 7/8	2 1/2	4 7/32	26
1 1/4	2	1 7/16	2 11/32	1 21/32	2 11/16	1 7/8	3 1/32	2 1/16	3 3/8	2 9/32	3 11/16	2 1/2	4 1/32	28
1 1/4	1 31/32	1 15/32	2 9/32	1 11/16	2 5/8	1 29/32	2 15/16	2 3/32	3 9/32	2 5/16	3 19/32	2 17/32	3 15/16	30
1 5/16	1 25/32	1 17/32	2 1/16	1 3/4	2 3/8	1 31/32	2 11/16	2 3/16	2 31/32	2 13/32	3 1/4	2 5/8	3 9/16	40
1 11/32	1 11/16	1 9/16	1 31/32	1 13/16	2 1/4	2 1/32	2 17/32	2 1/4	2 13/16	2 1/2	3 3/32	2 23/32	3 3/8	60
1 13/32	1 5/8	1 5/8	1 29/32	1 7/8	2 3/16	2 3/32	2 15/32	2 11/32	2 3/4	2 9/16	3	2 13/16	3 9/32	80
1 13/32	1 19/32	1 5/8	1 7/8	1 7/8	2 1/8	2 3/32	2 13/32	2 11/32	2 21/32	2 9/16	2 15/16	2 13/16	3 3/16	100
1 1/2	1 1/2	1 3/4	1 3/4	2	2	2 1/4	2 1/4	2 1/2	2 1/2	2 3/4	2 3/4	3	3	Rack

RCLES OF CENTRES AND FOR TOOTH CURVES. (*In Inches.*)

Involute Teeth.

1½"		1¾"		2"		2¼"		2½"		2¾"		3" Pitch		
Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Teeth
3 23/32	15/16	4 5/16	1 7/8	4 31/32	1 9/32	5 9/16	1 7/16	6 3/16	1 13/32	6 25/32	1 3/4	7 13/32	1 29/32	16
3 15/16	1	4 19/32	1 3/16	5 1/4	1 11/32	5 29/32	1 17/32	6 19/32	1 11/16	7 7/32	1 27/32	7 7/8	2 1/32	17
4 3/16	1 1/16	4 27/32	1 1/4	5 9/16	1 7/16	6 1/4	1 5/8	6 15/16	1 25/32	7 5/8	1 31/32	8 11/32	2 5/32	18
4 13/32	1 1/8	5 1/8	1 5/16	5 7/8	1 1/2	6 19/32	1 11/16	7 11/32	1 7/8	8 1/16	2 1/16	8 25/32	2 1/4	19
4 5/8	1 3/16	5 13/32	1 3/8	6 3/16	1 19/32	6 15/16	1 25/32	7 23/32	2	8 1/2	2 3/16	9 9/32	2 3/8	20
5 3/32	1 5/16	5 15/16	1 17/32	6 25/32	1 3/4	7 5/8	1 31/32	8 1/2	2 3/16	9 11/32	2 13/32	10 3/16	2 5/8	22
5 9/16	1 7/16	6 1/2	1 11/16	7 13/32	1 29/32	8 11/32	2 5/32	9 9/32	2 3/8	10 3/16	2 5/8	11 1/8	2 7/8	24
6 1/32	1 9/16	7 1/32	1 13/16	8 1/32	2 1/16	9 1/32	2 5/16	10 1/32	2 19/32	11 1/32	2 27/32	12 1/16	3 3/32	26
6 1/2	1 11/16	7 9/16	1 15/16	8 5/8	2 7/32	9 23/32	2 1/2	10 13/16	2 25/32	11 7/8	3 1/16	12 31/32	3 11/32	28
6 15/16	1 25/32	8 1/8	2 1/32	9 9/32	2 3/8	10 13/32	2 11/16	11 9/16	3	12 3/4	3 9/32	13 29/32	3 9/16	30
9 9/32	2 3/8	10 13/16	2 25/32	12 11/32	3 3/16	13 29/32	3 9/16	15 7/16	3 31/32	17	4 3/8	18 17/32	4 25/32	40
13 29/32	3 9/16	16 7/32	4 3/16	18 17/32	4 25/32	20 27/32	5 3/8	23 5/32	5 31/32	25 1/2	6 9/16	27 13/16	7 5/32	60
18 17/32	4 25/32	21 5/8	5 9/16	24 23/32	6 3/8	27 13/16	7 5/32	30 29/32	7 31/32	33 31/32	8 3/4	37 1/16	9 9/16	80
23 5/32	5 31/32	27 1/32	6 31/32	30 27/32	7 31/32	34 3/4	8 15/16	38 5/8	9 15/16	42 15/32	10 15/16	46 5/16	11 15/16	100

TABLE I.—DIAMETERS OF PITCH CIRCLES AND PROPORTIONS OF TEETH.

No. of Teeth	Pitch in Inches 1/2	3/4	1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3	No. of Teeth
12	1 15/16	2 7/8	3 13/16	4 3/4	5 3/4	6 11/16	7 5/8	8 5/8	9 9/16	10 1/2	11 7/16	12
13	2 1/16	3 1/8	4 1/8	5 3/16	6 3/16	7 1/4	8 1/4	9 5/16	10 3/8	11 3/8	12 7/16	13
14	2 1/4	3 3/8	4 7/16	5 9/16	6 11/16	7 13/16	8 15/16	10	11 1/8	12 1/4	13 3/8	14
15	2 3/8	3 9/16	4 3/4	6	7 3/16	8 3/8	9 9/16	10 3/4	11 15/16	13 1/8	14 5/16	15
16	2 9/16	3 13/16	5 1/8	6 3/8	7 5/8	8 7/8	10 3/16	11 7/16	12 3/4	14	15 1/4	16
17	2 11/16	4 1/16	5 7/16	6 3/4	8 1/8	9 1/2	10 13/16	12 3/16	13 9/16	14 7/8	16 1/4	17
18	2 7/8	4 5/16	5 3/4	7 3/16	8 5/8	10	11 7/16	12 7/8	14 5/16	15 3/4	17 3/16	18
19	3	4 9/16	6 1/16	7 9/16	9 1/16	10 9/16	12 1/8	13 5/8	15 1/8	16 5/8	18 1/8	19
20	3 3/16	4 3/4	6 3/8	8	9 9/16	11 1/8	12 3/4	14 5/16	15 15/16	17 1/2	19 1/8	20
22	3 1/2	5 1/4	7	8 3/4	10 1/2	12 1/4	14	15 3/4	17 1/2	19 1/4	21 1/8	22
24	3 13/16	5 3/4	7 5/8	9 9/16	11 7/16	13 3/8	15 1/4	17 3/16	19 1/8	21	22 15/16	24
26	4 1/8	6 3/16	8 1/4	10 3/8	12 7/16	14 1/2	16 9/16	18 5/8	20 11/16	22 3/4	24 13/16	26
28	4 7/16	6 11/16	8 15/16	11 1/8	13 3/8	15 5/8	17 13/16	20 1/16	22 5/16	24 1/2	26 3/4	28
30	4 3/4	7 3/16	9 9/16	11 15/16	14 5/16	16 3/4	19 1/8	21 1/2	23 7/8	26 1/4	28 5/8	30
40	6 3/8	9 9/16	12 3/4	15 15/16	19 1/8	22 1/4	25 7/16	28 5/8	31 13/16	35	38 3/16	40
60	9 9/16	14 5/16	19 1/8	23 7/8	28 5/8	33 7/16	38 3/16	43	47 3/4	52 1/2	57 5/16	60
80	12 3/4	19 1/8	25 7/16	31 13/16	38 3/16	44 9/16	50 15/16	57 5/16	63 11/16	70	76 3/8	80
100	15 15/16	23 7/8	31 13/16	39 3/4	47 3/4	55 3/4	63 11/16	71 5/8	79 9/16	87 1/2	95 1/2	100
Thickness	1/4	11/32	15/32	19/32	11/16	13/16	15/16	1 1/16	1 3/16	1 9/32	1 13/32	Thickness
Height of Face	5/32	1/4	11/32	7/16	1/2	19/32	11/16	3/4	27/32	15/16	1 1/32	Height of Face
Depth of Flank	7/32	5/16	13/32	1/2	19/32	23/32	13/16	29/32	1	1 1/8	1 7/32	Depth of Flank
Clearance	1/16	1/16	1/16	3/32	3/32	1/8	1/8	5/32	5/32	3/16	3/16	Clearance
Pitch	1/2"	3/4"	1"	1 1/4"	1 1/2"	1 3/4"	2"	2 1/4"	2 1/2"	2 3/4"	3"	Pitch

TABLE II.—RADII OF CIRCLES FOR CENTRES.

Pitch →	1/2"		3/4"		1"		1 1/4"		1 1/2"		1 3/4"		2"		2 1/4"		2 1/2"		2 3/4"		3" ← Pitch		
Teeth	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Teeth
12	15/16	—	1 3/8	—	1 27/32	—	2 5/16	—	2 25/32	—	3 1/4	—	3 23/32	—	4 3/16	—	4 21/32	—	5 1/8	—	5 19/32	—	12
13	1	3 5/8	1 1/2	5 5/16	2	7 1/4	2 1/2	9 1/16	3	10 7/8	3 1/2	12 11/16	4 1/32	14 1/2	4 17/32	16 5/16	5 1/32	18 1/8	5 17/32	19 15/16	6 1/32	21 3/4	13
14	1 1/16	2 1/4	1 5/8	3 3/8	2 3/16	4 1/2	2 11/16	5 5/8	3 7/32	6 3/4	3 3/4	7 7/8	4 5/16	9	4 13/16	10 1/8	5 11/32	11 1/4	6	12 3/8	6 7/16	13 1/2	14
15	1 5/32	1 29/32	1 3/4	2 7/8	2 11/32	3 13/16	2 15/16	4 25/32	3 1/2	5 3/4	4 3/32	6 11/16	4 11/16	7 5/8	5 5/16	8 19/32	5 7/8	9 9/16	6 15/32	10 1/2	7 1/32	11 7/16	15
16	1 1/4	1 13/16	1 7/8	2 11/16	2 1/2	3 19/32	3 1/8	4 1/2	3 3/4	5 13/32	4 3/8	6 5/16	4 31/32	7 7/32	5 19/32	8 1/8	6 7/32	9	6 27/32	9 29/32	7 15/32	10 13/16	16
17	1 5/16	1 3/4	1 31/32	2 5/8	2 5/8	3 1/2	3 5/16	4 3/8	3 15/16	5 1/4	4 5/8	6 1/8	5 5/16	7	5 15/16	7 7/8	6 9/16	8 3/4	7 1/4	9 5/8	7 29/32	10 1/2	17
18	1 11/32	1 1/2	2 1/16	2 3/8	2 11/16	3 17/32	3 1/2	4 23/32	4 1/16	5 29/32	4 23/32	6 5/32	5 13/32	7 1/16	6 1/16	7 15/16	7	8 13/16	7 23/32	9 11/16	8 13/32	10 19/32	18
19	1 1/4	1 11/16	2 3/16	2 17/32	2 31/32	3 3/8	3 21/32	4 7/32	4 7/16	5 1/16	5 1/8	6 15/32	5 7/8	7 1/4	6 11/16	8 5/32	7 5/16	9 1/16	8 5/32	9 31/32	8 27/32	10 7/8	19
20	1 3/16	1 27/32	2 13/16	2 3/4	3 1/8	3 11/16	3 29/32	4 5/8	4 11/16	5 1/2	5 15/32	6 7/16	6 1/4	7 3/8	7 1/32	8 5/16	7 13/16	9 1/4	8 19/32	10 5/32	9 3/8	11 1/16	20
22	1 23/32	1 11/16	2 5/8	2 17/32	3 7/16	3 29/32	4 5/16	4 29/32	5 5/32	5 7/8	6	6 29/32	6 7/8	7 13/16	7 3/4	8 11/16	8 19/32	9 23/32	9 7/16	10 5/8	10 5/16	11 19/32	22
24	1 7/8	2 3/16	2 13/16	3 1/4	3 3/4	4 3/8	4 11/16	5 1/4	5 5/8	6 9/16	6 9/16	7 5/8	7 1/2	8 3/4	8 7/16	9 13/16	9 3/8	10 15/16	10 5/16	11 1/2	11 1/4	12 1/16	24
26	2 1/16	2 1/4	3 1/16	3 5/16	4 1/16	4 15/32	5 1/16	5 19/32	6 3/32	6 11/16	7 3/32	7 13/16	8 1/8	8 15/16	9 1/8	10 1/16	10 1/16	11 3/16	11 5/32	12 5/16	12 3/16	13 15/32	26
28	2 3/16	2 3/8	3 5/16	3 9/16	4 3/8	4 3/4	5 15/32	5 15/16	6 9/16	7 1/8	7 21/32	8 5/16	8 3/4	9 1/2	9 27/32	10 11/16	10 15/16	11 7/8	12 1/32	13 1/16	13 1/8	14 1/4	28
30	2 9/32	2 17/32	3 13/32	3 13/16	4 11/16	5 1/16	5 5/8	6 5/16	7 1/16	7 5/8	8 5/32	8 7/8	9 13/32	10 1/8	10 13/32	11 3/8	11 1/2	12 5/8	12 21/32	13 29/32	14 1/16	15 3/16	30
40	3 1/8	3 3/32	4 11/16	4 11/16	6 3/32	6 13/32	7 23/32	8 1/4	9 3/16	9 7/8	11	11 17/32	12 3/16	13 3/16	14 1/8	14 7/8	15 11/16	16 1/2	17 1/4	18 1/8	18 27/32	19 25/32	40
60	4 3/4	4 7/8	7 1/32	7 5/16	9 13/32	9 3/4	11 23/32	12 3/16	14 1/16	14 5/8	16 3/8	17 1/16	18 13/16	19 1/2	21 1/8	21 15/16	23 15/32	24 3/8	26 1/32	26 13/16	28 3/32	29 1/4	60
80	6 3/16	6 11/16	9 15/32	10 3/32	12 5/8	13 1/4	15 25/32	17 11/32	18 15/16	20 3/16	22 1/16	24 3/32	25 1/4	27 3/4	28 13/32	31 5/32	31 9/16	34 11/16	34 23/32	38 5/32	37 7/8	41 5/8	80
100	7 27/32	8 3/16	11 27/32	12 1/4	15 11/16	16 3/16	19 3/4	20 1/16	23 21/32	24 1/8	27 21/32	28 1/4	31 5/8	32 1/4	35 3/8	36 1/4	39 1/2	40 5/8	43 15/32	44 3/16	47 7/16	48 3/16	100
Rack	−1/16	+1/16	−3/32	+3/32	−1/8	+1/8	−5/32	+5/32	−3/16	+3/16	−7/32	+7/32	−1/4	+1/4	−9/32	+9/32	−5/16	+5/16	−11/32	+11/32	−3/8	+3/8	Rack

TABLE III.—RADII FOR TOOTH CURVES

Pitch →	1/2"		3/4"		1"		1 1/4"		1 1/2"		1 3/4"		2"		2 1/4"		2 1/2"		2 3/4"		3" ← Pitch		
Teeth	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Fa.	Fl.	Teeth
12	3/8	—	9/16	—	3/4	—	15/16	—	1 1/8	—	1 5/16	—	1 15/32	—	1 21/32	—	1 27/32	—	2 1/32	—	2 7/32	—	12
13	3/8	3 15/32	9/16	5 3/16	3/4	6 15/16	15/16	8 11/16	1 1/8	10 3/8	1 5/16	12 1/8	1 1/2	13 7/8	1 11/16	15 5/8	1 7/8	17 5/16	2 1/16	19 1/32	2 1/4	20 3/4	13
14	3/8	1 15/16	9/16	2 29/32	3/4	3 7/8	15/16	4 27/32	1 1/8	5 13/16	1 5/16	6 25/32	1 1/2	7 3/4	1 11/16	8 23/32	1 7/8	9 11/16	2 1/16	10 21/32	2 1/4	11 5/8	14
15	3/8	1 15/32	9/16	2 3/16	3/4	2 15/16	15/16	3 21/32	1 1/8	4 13/32	1 5/16	5 1/8	1 17/32	5 7/8	1 23/32	6 19/32	1 29/32	7 5/16	2 3/32	8 1/16	2 9/32	8 3/4	15
16	3/8	1 7/32	9/16	1 27/32	3/4	2 7/16	15/16	3 1/16	1 1/8	3 21/32	1 5/16	4 1/4	1 17/32	4 7/8	1 23/32	5 1/2	1 29/32	6 3/32	2 3/32	6 23/32	2 9/32	7 5/16	16
17	3/8	1 1/16	19/32	1 19/32	25/32	2 1/8	31/32	2 21/32	1 5/32	3 3/16	1 11/32	3 23/32	1 9/16	4 1/4	1 3/4	4 25/32	1 15/16	5 5/16	2 1/8	5 27/32	2 11/32	6 3/8	17
18	3/8	31/32	19/32	1 3/8	25/32	1 13/16	31/32	2 5/16	1 5/32	2 25/32	1 11/32	3 1/4	1 9/16	3 3/4	1 3/4	4 1/8	1 15/16	4 19/32	2 1/8	5 1/16	2 5/16	5 9/16	18
19	13/32	27/32	19/32	1 1/4	13/16	1 11/16	1	2 1/8	1 7/32	2 17/32	1 3/8	3 1/16	1 19/32	3 3/8	1 13/16	4 3/32	2	4 7/32	2 3/16	4 21/32	2 13/32	5 7/16	19
20	13/32	7/8	19/32	1 9/32	13/16	1 21/32	1	2 1/32	1 3/16	2 7/16	1 3/8	3	1 19/32	3 3/16	1 13/16	3 5/8	2	4 3/16	2 3/16	4 15/32	2 13/32	5 5/32	20
22	13/32	25/32	19/32	1 3/16	13/16	1 9/16	1	1 15/16	1 3/16	2 5/16	1 13/32	2 3/4	1 5/8	3 1/8	1 13/16	3 1/2	2 1/32	3 29/32	2 1/4	4 9/32	2 7/16	4 11/16	22
24	13/32	3/4	19/32	1 1/16	13/16	1 13/32	1	1 25/32	1 7/32	2 1/8	1 13/32	2 7/16	1 5/8	2 13/16	1 27/32	3 5/32	2 1/32	3 1/2	2 1/4	4 1/32	2 7/16	4 7/32	24
26	13/32	23/32	5/8	1 1/16	13/16	1 13/32	1 1/32	1 3/4	1 1/4	2 1/16	1 7/16	2 13/32	1 21/32	2 11/16	1 7/8	3 1/32	2 1/16	3 3/8	2 9/32	3 5/8	2 1/2	4 1/32	26
28	13/32	11/16	5/8	1	13/16	1 5/16	1 1/32	1 5/8	1 1/4	2	1 7/16	2 9/32	1 21/32	2 11/16	1 7/8	3 1/32	2 1/4	3 3/8	2 9/32	3 5/8	2 1/2	4 1/32	28
30	7/16	21/32	5/8	31/32	[illegible]	1 5/16	1 1/16	1 5/8	1 1/4	1 29/32	1 15/32	2 7/32	1 11/16	2 1/2	1 29/32	2 13/16	2 1/16	3 1/16	2 5/16	3 13/32	2 17/32	3 3/4	30
40	7/16	19/32	21/32	7/8	7/8	1 1/16	1 3/32	1 1/4	1 5/16	1 17/32	1 17/32	2 1/16	1 3/4	2 1/8	1 31/32	2 11/32	2 3/16	2 9/16	2 13/32	3 1/4	2 5/8	3 3/8	40
60	7/16	9/16	11/16	27/32	29/32	1 1/8	1 1/8	1 13/32	1 11/32	1 11/16	1 9/16	1 31/32	1 13/16	2 1/4	2 1/32	2 17/32	2 1/4	2 27/32	2 1/2	3 3/32	2 23/32	3 3/8	60
80	15/32	17/32	11/16	13/16	15/16	1 1/16	1 5/32	1 3/8	1 13/32	1 5/8	1 5/8	1 29/32	1 7/8	2 3/16	2 1/16	2 15/32	2 11/32	2 3/4	2 9/16	3	2 13/16	3 5/16	80
100	15/32	17/32	11/16	25/32	15/16	1 1/16	1 5/32	1 5/16	1 13/32	1 19/32	1 5/8	1 7/8	1 7/8	2 1/8	2 1/16	2 13/32	2 11/32	2 21/32	2 5/8	2 29/32	2 13/16	3 3/16	100
Rack	1/2	1/2	3/4	3/4	1	1	1 1/4	1 1/4	1 1/2	1 1/2	1 3/4	1 3/4	2	2	2 1/4	2 1/4	2 1/2	2 1/2	2 3/4	2 3/4	3	3	Rack

TABLE IV.—RADII FOR CIRCLES OF CENTRES AND FOR TOOTH CURVES. (*In Inches.*)

Involute Teeth.

Pitch	1/2"		3/4"		1"		1 1/4"		1 1/2"		1 3/4"		2"		2 1/4"		2 1/2"		2 3/4"		3" Pitch		
Teeth	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Cen.	Cur.	Teeth
16	1 1/4	5/16	1 27/32	15/32	2 15/32	5/8	3 3/32	13/16	3 23/32	15/16	4 5/16	1 3/32	4 31/32	1 9/32	5 9/16	1 7/16	6 3/16	1 19/32	6 25/32	1 3/4	7 13/32	1 29/32	16
17	1 5/16	11/32	1 31/32	1/2	2 21/32	11/16	3 9/32	27/32	3 15/16	1	4 19/32	1 3/16	5 1/4	1 11/32	5 29/32	1 17/32	6 19/32	1 11/16	7 7/32	1 27/32	7 7/8	2 1/32	17
18	1 13/32	3/8	2 3/32	17/32	2 25/32	23/32	3 15/32	29/32	4 3/16	1 1/16	4 27/32	1 1/4	5 9/16	1 7/16	6 1/4	1 5/8	6 15/16	1 25/32	7 5/8	1 31/32	8 11/32	2 5/32	18
19	1 15/32	3/8	2 7/32	9/16	2 15/16	3/4	3 21/32	15/16	4 13/32	1 1/8	5 1/8	1 5/16	5 7/8	1 1/2	6 19/32	1 11/16	7 11/32	1 7/8	8 1/16	2 1/16	8 25/32	2 1/4	19
20	1 9/16	13/32	2 5/16	19/32	3 3/32	13/16	3 7/8	1	4 5/8	1 3/16	5 13/32	1 3/8	6 3/16	1 19/32	6 15/16	1 25/32	7 23/32	2	8 1/2	2 3/16	9 9/32	2 3/8	20
22	1 23/32	7/16	2 9/16	21/32	3 13/32	7/8	4 1/4	1 3/32	5 3/32	1 5/16	5 15/16	1 17/32	6 25/32	1 3/4	7 5/8	1 31/32	8 1/2	2 3/16	9 11/32	2 13/32	10 3/16	2 5/8	22
24	1 27/32	15/32	2 13/16	23/32	3 23/32	15/16	4 5/8	1 3/16	5 9/16	1 7/16	6 1/2	1 11/16	7 13/32	1 29/32	8 11/32	2 5/32	9 9/32	2 3/8	10 3/16	2 5/8	11 1/8	2 7/8	24
26	2	1/2	3	25/32	4	1 1/32	5 1/32	1 9/32	6 1/32	1 9/16	7 1/32	1 13/16	8 1/32	2 1/16	9 1/32	2 5/16	10 1/32	2 19/32	11 1/32	2 27/32	12 1/16	3 3/32	26
28	2 5/32	9/16	3 1/4	27/32	4 5/16	1 1/8	5 13/32	1 3/8	6 1/2	1 11/16	7 9/16	1 15/16	8 5/8	2 7/32	9 23/32	2 1/2	10 13/16	2 25/32	11 7/8	3 1/16	12 31/32	3 11/32	28
30	2 5/16	19/32	3 15/32	29/32	4 5/8	1 3/16	5 25/32	1 1/2	6 15/16	1 25/32	8 1/8	2 3/32	9 9/32	2 3/8	10 13/32	2 11/16	11 9/16	3	12 3/4	3 9/32	13 29/32	3 9/16	30
40	3 3/32	13/16	4 5/8	1 3/16	6 3/16	1 19/32	7 23/32	2	9 9/32	2 3/8	10 13/16	2 25/32	12 11/32	3 3/16	13 29/32	3 9/16	15 7/16	3 31/32	17	4 3/8	18 17/32	4 25/32	40
60	4 5/8	1 3/16	6 15/16	1 25/32	9 9/32	2 3/8	11 19/32	3	13 29/32	3 9/16	16 7/32	4 3/16	18 17/32	4 25/32	20 27/32	5 3/8	23 5/32	5 31/32	25 1/2	6 9/16	27 13/16	7 5/32	60
80	6 3/16	1 19/32	9 9/32	2 3/8	12 11/32	3 3/16	15 7/16	3 31/32	18 17/32	4 25/32	21 5/8	5 9/16	24 23/32	6 3/8	27 13/16	7 5/32	30 29/32	7 31/32	33 31/32	8 3/4	37 1/16	9 9/16	80
100	7 23/32	2	11 19/32	3	15 7/16	3 31/32	19 5/16	4 31/32	23 5/32	5 31/32	27 1/32	6 31/32	30 27/32	7 31/32	34 3/4	8 15/16	38 5/8	9 15/16	42 15/32	10 15/16	46 3/8	11 15/16	100

tion point will be the radii, for face and flank curves. Through these two centres and concentric with the pitch circle draw *circles of centres for face* and *for flank curves;* and with centres on these, and the respective radii found above, draw all tooth curves, and fillet the root corners to a radius of ·07 p, the clearance.

TO DRAW INVOLUTE TEETH APPROXIMATELY BY CIRCULAR ARCS.

Case I: The Rack.—Draw the pitch line and mark on it the pitch points. Draw limiting lines for the total height of the teeth, parallel to the pitch line. Through the pitch points draw *straight lines* for the sides of the teeth at 75° to the pitch line.

Case II: The Wheel.—Draw the pitch circle and mark on it the pitch points. Concentric with it, draw limiting lines for the total height of the teeth, and a *circle of centres* whose radius is $\frac{31}{32}$ or ·97 of the pitch radius. With centres on this circle and a radius equal to ·25 of the pitch radius, draw the face curves through the pitch points outward from the circle of centres, and finish the flanks by straight, radial lines, filleting the root corners to a radius of ·07 p.

CENTRAL STATION LIGHTING.*

By Pedro G. Salom.

The advantage of using storage batteries in central station lighting may briefly be summed up as follows:

(I) They effect a substantial saving in operating expenses.

(II) They increase the factor of safety.

(III) They permit of a material extension of distribution without increasing the size of the power plant.

(*I*) *As to the saving in operating expenses.*

As the question of economy is largely the determining factor as to the advisability of introducing a battery, let us examine more at length the means by which this is effected.

(*a*) By taking care of the crown of the maximum load when all the generating machinery is taxed to its utmost extent.

(*b*) By dispensing with one shift of labor in taking care of the entire minimum load.

(*c*) By permitting the operation of large units exclusively.

(*d*) By operating all the units at their maximum load and hence at their maximum efficiency.

As to the maximum load. Owing to the peculiar nature of electric lighting it frequently happens that the number of units generated at the maximum load is not more than a few per cent. of that of the total average load, and the total load is only a few per cent. in summer and rarely above forty per cent. in winter of the total possible output of the plant.

The first requisite, therefore, in determining whether a battery can advantageously be introduced in any given central station, and if so what its size or capacity shall be, is to have diagrams of the load curves.

The next important factor is the number and size of the units employed at the station. From these data we determine what has very appropriately been called the load factor, and then it is easy and simple to calculate the size of the battery required to give the most economical operating

* Read at the stated meeting of the Institute, held December 20, 1893.

results. Once the size of the battery is determined, we can calculate the saving effected:

(*a*) By dispensing with a night shift.

(*b*) By diminishing the consumption of coal for a given output.

(*c*) By the saving effected in operating a few large units of one size, instead of a number of small units of various sizes.

(*d*) By the saving effected in operating each unit at its maximum efficiency.

(*e*) By the additional revenues from increase of total output taken from battery at time of maximum load.

As the item of labor in small stations is frequently as high as twenty-five per cent. of the operating expenses, the saving effected by dispensing with a night shift is not inconsiderable.

By operating large units exclusively there is also a material saving effected both in labor and in the much higher efficiencies of large over small units.

Again, as the coal bill is the largest item of expense, amounting in some cases to more than fifty per cent. of the total operating expenses, any saving effected in this item is of paramount importance, and is reflected at once in the decrease of operating expenses.

The question of mechanical efficiency with varying loads has not been as carefully studied with each type of engine as its importance deserves, but Prof. W. Cawthorne Unwin, F.R.S., has shown that the decrease of mechanical efficiency for light loads has a serious effect on the economy of working with a variable load, and that with a load varying from 100 to 25 per cent. the efficiency decreases from eighty-five to forty per cent.

While it is impossible to say in a general way what the exact saving would be from the introduction of a battery of sufficient size to permit of the operation of all the units at maximum load (since the load is not the same in any two central stations), the results prove that in central stations equipped with storage batteries the operating expenses are diminished as much as thirty per cent.

(*II*) *As to the factor of safety.*

In case there is a derangement or break-down of the generating machinery, or where the steam pressure cannot be kept up to a sufficiently high point to operate all the units at maximum load, the elasticity of a storage battery permits of an immediate discharge rate enormously in excess of its normal rate. In other words, a battery designed for a given output could in emergencies be safely called upon for one half hour or more to deliver a current three times as great as that for which it was designed.

This is a fact of vital importance, and one which any central station man will at once appreciate, for in any direct system of transmission there is always the liability of a derangement or break-down of one of the links in the chain, whereas in a central station equipped with a storage battery the manager can depend on the battery to take the load of an individual unit until such time as the derangement or break-down can be remedied or repaired. Moreover, it frequently happens, where the business of a central station has increased since the original introduction of its generating machinery, that the boiler capacity at maximum load is so taxed that it is difficult to maintain steam pressure sufficient to operate all the units at once, in which case, if a battery is employed, recourse may be had to the battery until such time as the engineer shall be able to keep steam up to the required pressure.

(*III*) *As to the question of distribution.*

The advantages of the use of storage batteries under this head follow as a corollary from what has been said in the previous paragraphs, but the application is much wider than has been previously intimated. For example, when a central station has supplied the demand within a given radius of economical distribution and a demand arises for electric light or power immediately adjacent to and outside of this given radius of distribution, it is possible to supply this demand by having sub-stations of storage batteries. These may be charged by a special wire at comparatively high pressure during the day, thus increasing the average load of the central station, and their charge distributed at

night from the sub-stations at the regular pressure. The central station is thus enabled materially to increase its revenues without increasing its original power plant. An economy is effected also in this method of distribution by decreasing the size of the feeders to the outlying districts, since it is possible to charge the batteries used at a comparatively low rate for ten or twelve hours, whereas by direct lighting the feeders would have to be large enough to carry the entire load of the sub-station at its maximum output, which might only last for two or three hours.

In addition to the saving effected in operating expenses, the use of a battery may be made to yield additional revenues in proportion to the amount of current supplied to the circuit over and above what the direct system, at the time of maximum load, could supply without increasing the size of the power plant.

From what has been said above it is evident that central station lighting is one of the most important fields of usefulness of the storage battery and one which has hardly yet been touched upon.

The same arguments apply with increased force to its application in a power house for electric traction. Here the variation in the load is between such wide limits and of such a sudden character as to render it impossible to operate the power plant on anything like an economical basis.

In all such cases, by the introduction of a sufficiently large battery, the load curve, instead of resembling a stroke of lightning as it does at present, could be perfectly equalized, enabling the power plant to operate at full load and maximum efficiency.

The following list of central stations employing storage batteries in England and on the continent will give some idea of the extent of their adoption in those countries:

England.—Kensington Central Station, Gothenburg Electric Supply Company, Westminster Electric Supply Corporation (Limited), Knightsbridge Central Station, Houses of Parliament, Cadogan Electric Supply Company (Limited), Bradford Electric Supply Corporation (Limited), Liverpool Electric Supply Company (Limited), Northampton Electric

Light and Power Company (Limited), Notting Hill Electric Lighting Company (Limited), Southampton Electric Light and Power Company (Limited), Birmingham Electric Supply Company (Limited).

Germany.—Berlin (Thiergarten district); Königsberg, in Prussia; Stettin, Breslau, Hamburg, Lübeck, Bremen, Hannover, Erfurt, Cassel, Eisenach, Gera, Blankenburg, Osterade, Geestemünde, Düsseldorf, Barmen, Hagen, Gevelsberg, Gummersbach, Corbach, Marburg, Aix-la-Chapelle, Meiningen, Dessau, Bochum, Mühlhausen, Berchtesgaden, Hart, Zwickau, Hornberg.

Holland and Belgium.—Hague, Brussels, Dolhain, Ghent, Ninove, Westeras.

Sweden, Norway and Denmark.—Stockholm, Christiania, Copenhagen.

Italy and Spain.—Naples, Genoa, Ferrara, Madrid, Santander.

Switzerland.—Bern, Aarau.

France.—Paris, Secteur, Clichy, Lyons, Reims, Lille, Sedan.

TABLE NO. 1.—TYPE C. S.

Horse-power.	Kilowatts.	Voltage on Mains.	Maximum Rate of Discharge in Ampères.	Total Ampère-hour Capacity when Discharged in 3 hrs.	5 hrs.	7 hrs.	10 hrs.	Number of Accumulators in Series.	Number of Couples (Positive and Negative Plate) in each Accumulator.	Approximate Area in Square Feet Covered by Battery Alone.	Approximate Weight of Elements, in Pounds.
1	0·746	110	6	18	20	22	24	60	1	12	600
10	7·46	110	60	180	200	220	240	60	10	70	6,000
20	14·92	110	120	360	400	440	480	60	20	140	12,000
30	22·38	110	180	540	600	660	720	60	30	210	18,000
50	37·30	110	[illegible]	900	1,000	1,100	1,200	60	50	360	30,000
100	74·6	110	600	1,800	2,000	2,200	2,400	60	100	350	60,000
200	149·2	110	1,200	3,600	4,000	4,400	4,800	60	200	700	120,000
300	223·8	110	1,800	5,400	6,000	6,600	7,700	60	300	1,050	180,000
400	298·4	110	2,400	7,[illegible]00	8,000	8,800	9,600	60	400	1,400	240 000
500	373·	110	[illegible]	9,000	10,000	11,000	12,000	60	500	1,750	300,000

NOTE.—The above table is based on sixty accumulators for a 110-volt circuit; for other potentials a proportionate number of accumulators is required.

TABLE NO. 2.—TYPE C. S.

Trade Number.	Number of Accumulators.	Number of Couples.	Voltage.	Time of Discharge, in Hours.	Rate of Discharge, in Ampères.	Ampère-hour Capacity at Different Rates of Discharge.	Horse-power.	Approximate Area in Square Feet Covered by Battery Alone.	Approximate Weight of Elements, in Pounds.
1	60	6	110	3	33	100	6	40	3,600
				5	22	111			
				7	17	122			
				10	13	133			
2	60	11	110	3	66	200	11	88	6,600
				5	44	222			
				7	35	244			
				10	26	266			
3	60	17	110	3	100	300	17	120	10,200
				5	66	333			
				7	51	366			
				10	40	400			
4	60	22	110	3	133	400	22	160	13,200
				5	88	444			
				7	68	488			
				10	53	532			
5	60	28	110	3	166	500	28	200	16,800
				5	111	555			
				7	87	610			
				10	66	665			
6	60	33	110	3	200	600	33	240	19,800
				5	133	666			
				7	104	732			
				10	79	798			
7	60	39	110	3	233	700	39	280	23,400
				5	155	777			
				7	122	854			
				10	93	931			
8	60	45	110	3	266	800	45	320	26,400
				5	177	888			
				7	139	976			
				10	106	1,064			
9	60	50	110	3	300	900	50	360	30,000
				5	200	999			
				7	157	1,098			
				10	119	1,197			
10	60	55	110	3	333	1,000	55	175	33,000
				5	222	1,110			
				7	174	1,220			
				10	130	1,330			
11	60	110	110	3	607	2,000	110	350	66,000
				5	444	2,220			
				7	350	2,440			
				10	266	2,660			
12	60	165	110	3	1,000	3,000	165	525	99,000
				5	666	3,330			
				7	523	3,660			
				10	400	4,000			
13	60	220	110	3	1,333	4,000	220	700	132,000
				5	888	4,440			
				7	697	4,880			
				10	532	5,320			
14	60	275	110	3	1,666	5,000	275	875	165,000
				5	1,110	5,550			
				7	872	6,100			
				10	665	6,650			

NOTE.—Nos. 1 to 9, inclusive, height, 9 inches. Nos. 10 to 14, inclusive, height, 18 inches. No allowance made for space between cells.

The above table is based on sixty accumulators for a 110-volt circuit; for other potentials a proportionate number of accumulators is required.

ON THE DETERMINATION OF PHOSPHORIC ACID.*

BY H. PEMBERTON, JR.

Last autumn I described a process for determining phosphoric acid by titration of the ammonium phospho-molybdate with standard alkali. (This *Journal*, **136**, 362.) The ratio between the P_2O_5 of the precipitate and the standard alkali was determined and found to be 23·2 molecules of Na_2O to one molecule of P_2O_5. Upon this ratio, as determined by direct analysis, the standard solution was prepared of such strength that one cubic centimeter should be equal to one milligram of P_2O_5 by diluting 326·5 cubic centimeters of normal alkali to one litre. The analyses upon which this ratio (23·2 molecules) was determined were carefully made. I was, therefore, at a loss to know the cause of the variation of this figure from the theoretical ratio of exactly 23 molecules of Na_2O. The difference is of more importance than might, at first thought, be supposed, because the strength of the alkali solution is based upon the figure determined empirically, and not upon the theoretical one. If the 23·2 proportion is wrong and 23 correct, a standard solution based upon the former ratio would give too low results in the proportion of 23·2 : 23·0. Thus, a phosphate rock containing 80 per cent. bone phosphate of lime would appear, by such an analysis, to contain only 79·31 per cent.

It was decided, therefore, to repeat this part of the work, and in this re-examination the conditions were the same as those previously existing, except in one particular: the amount of phosphoric acid operated upon was smaller than that previously used. By referring to the original paper, it will be found that about 80 cubic centimeters of alkali were used in each of the titrations in question. This represents a quantity of the yellow precipitate much larger than would ever be obtained in the examination of even the

* Read at the stated meeting of the Chemical Section, held February 20, 1894.

richest phosphate rocks; and in operating upon so large a precipitate the liability of error from incomplete washing is great. Any free acid remaining in the precipitate would, of course, result in too high a reading of the burette, with a corresponding error in the standardizing of the solution.

The following are the results obtained in this re-examination:

Some di-sodic hydric phosphate, bought as chemically pure, was dissolved in hot distilled water, filtered, and crystallized, the crystals were washed, dissolved again in water, and re-crystallized. Of the resulting crop of crystals, about 45 grams were dissolved in one-half litre of water. The strength of this solution was then determined

	Weight of Na_2HPO_4 Solution. Grams.		*Grams*
I,	20·0814	gave	0·7581 $Na_4P_2O_7$
II,	17·9585	gave	0·6778 $Na_4P_2O_7$
III,	36·9115	gave	1·1652 $Mg_2P_2O_7$

The magnesium-ammonium phosphate precipitate was filtered, dissolved in acid and re-precipitated by ammonia.

By a coincidence each of these three determinations gave precisely the same result, viz:

TABLE I.

	Grams. P_2O_5 in 10 grams of Solution.
I,	= ·2014
II,	= ·2014
III,	= ·2014

Therefore, ten grams of the phosphate of soda solution contained 0·2014 grams P_2O_5.

Weighed portions of this same solution were now precipitated by ammonic molybdate, thoroughly washed and titrated. The results are given in Table II.

TABLE II.

I.	*II. Grams Na_2HPO_4 Solution taken.*	*III. Equivalent to Grams P_2O_5.*	*IV. CC. of KHO Solution used.*
A,	2·0410	0·04110	41·05
B,	2·3710	0·04775	47·70
C,	2·2920	0·04616	46·20
D,	2·4690	0·04972	49·60

Dividing the figures in Column III by those in Column IV, and multiplying the result by 100, we obtain the number of milligrams corresponding to 100 cubic centimeters of the KHO solution, as follows:

TABLE III.

	Mgrs. P_2O_5
A,	= 100·12
B,	= 100·11
C,	= 99·91
D,	= 100·24
Average,	= 100·09

Therefore, 100 cubic centimeters of the KHO solution neutralize an amount of the yellow precipitate corresponding to 100·09 milligrams of P_2O_5.

The standard acid was now titrated against the standard alkali, using phenolphthalein as the indicator, whereby the two solutions were found to be of exactly equal strength.

The standard acid was then titrated against pure sodium carbonate, using phenolphthalein at boiling heat:

	Grams Na_2CO_3 used.	CC. of Acid used.	100 cc. Acid equal to Mgrs. Na_2CO_3.
I,	0·9099	52·95	1,719
II,	0·9168	53·35	1,719

Therefore, 100 cubic centimeters acid are equivalent to 1,719 milligrams Na_2CO_3, and since the alkali solution is of the same strength as the acid, 100 cubic centimeters of it also are equivalent to 1,719 milligrams Na_2CO_3.

As we have already seen, by Table III, that 100 cubic centimeters of the alkali are required to neutralize 100·09 milligrams of P_2O_5 (in the form of ammonium phospho-molybdate), it follows that 1,719 milligrams Na_2CO_3 are required for 100·09 milligrams P_2O_5.

Dividing each by its molecular weight, we have

$$\text{for } P_2O_5 \quad \frac{100{\cdot}09}{142{\cdot}06} = {\cdot}7045$$

$$\text{for } Na_2CO_3 \quad \frac{1{,}719}{106{\cdot}1} = 16{\cdot}20$$

Therefore,

$$P_2O_5 : Na_2CO_3 = {\cdot}7045 : 16{\cdot}20 = 1 : 22{\cdot}99$$

In other words, 23 molecules of Na_2CO_3 (or of Na_2O) are required to neutralize the yellow precipitate containing one molecule of P_2O_5, and the former figure (that given in my paper of last autumn) 23·2 molecules, is incorrect.

Referring to Table II of the present paper, it may be stated that in Analysis A the yellow precipitate was washed on an ordinary filter without using suction, the precipitate being washed on the filter, transferred to the beaker and then again filtered and washed. In Analysis B, of the same table, the precipitate was washed on the ordinary filter, with the aid of the suction pump. In Analyses C and D, the precipitates were washed with suction on a porcelain funnel with a fixed perforated plate in it. This form of funnel is known as the Hirsch funnel.*

As in all cases the results were nearly identical, it is evident that the different methods of washing the precipitate had no influence upon the result. Exactly twenty-three molecules of Na_2O are required for one molecule of P_2O_5. The standard acid is prepared by diluting 323·7 cubic centimeters of normal sulphuric acid to one litre, and not 326·5 cubic centimeters, as previously stated. The alkali solution, after removing CO_2 by $Ba(HO)_2$, is brought to the same strength as the acid, volume for volume.

One cubic centimeter of either solution is then equal to one milligram of P_2O_5.

PHILADELPHIA, PA.,
February 20, 1894.

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*To be had from Bullock & Crenshaw, Philadelphia. A disc of filter paper of the diameter of an American silver quarter dollar (fifteen-sixteenths inch) is used, when employing the smallest size funnel. I can highly recommend this funnel in all cases in which the precipitate is to be titrated. The precipitate presents a perfectly flat surface, is easily and quickly washed, and is readily transferred to the beaker with the aid of the wash-bottle. This funnel can be employed only when using the suction pump, but it has the advantage of not requiring a platinum cone, and the size of the filter is reduced to a minimum.

THE RESISTANCE OF SHIPS.

BY RICHARD LANO NEWMAN.

[*A paper read before the Section of Engineers and Naval Architects January 24, 1894.*]

[*Concluded from p. 233.*]

Up to the present we have assumed that the stream lines retain their horizontal flow, but it would be as well to state that this is not generally accepted as correct.

Scott Russell says: "At the foremost part of a ship the particles move in layers which are almost horizontal, while at the stern the particles have a considerable vertical component in their motion, besides converging laterally." How this vertical component can exist only at the stern and not at the bow, seems to me to be altogether unaccountable. There must of necessity have been a source of supply to have obtained this vertical component, and that supply could only have been obtained by the existence of corresponding conditions at the bow. It, therefore, seems that Professor Rankine's conclusions are more nearly correct. He says: "The actual paths of the particles of water in gliding over the bottom of a vessel are neither horizontal waterlines nor vertical buttock lines, but are intermediate in position between those lines, and approximate in well shaped vessels to the lines of shortest distance, such as are followed by an originally straight strake of plank, when bent to fit the shape of the vessel!" But, whatever paths may be followed, if the particles, at a considerable distance astern of a ship wholly submerged in a frictionless fluid, have regained their original direction and speed of flow, which they had at a considerable distance ahead of the ship, then their flow past the ship will impress no end-wise motion upon her.

Professor Rankine has laid down geometrical rules for constructing the paths along which the particles of a fric-

tionless fluid would flow in passing a body very deeply submerged, but as it would occupy too much time to investigate the subject, I would refer those desirous of doing so to pages 106-107, of his *Ship-building, Theoretical and Practical.*

As before stated, a frictionless fluid, on passing a body wholly submerged, will impress no end-wise motion upon her, nor (providing she is submerged sufficiently deep) will there be any surface disturbances, but this last-named condition does not hold good in a body only partly immersed, as is a ship. At the bows the streams will receive a check in their velocity. This check means an increase of pressure, and hence a wave-crest will be formed at the bow. Amidships, where the conditions are reversed, that is, where increase in the velocity of the stream lines means decrease of pressure, the water might fall some distance below its normal level. At the stern, where the conditions are somewhat similar to those at the bow, another wave-crest will be formed. There are other waves which would probably exist between bow and stern, and to which I propose to refer at a later stage, should time permit. Every one readily sees why a wave is formed at the bow, but it is more difficult to account for the existence of one at the stern. The reasoning generally accepted for the one is is also assumed to hold good for the other, viz: The surface of the water is subjected to a uniform pressure, *i. e.*, atmospheric pressure, and any diminution or increase of pressure caused by the fluctuation of the speed of flow past the ship, will be apparent by a depression below, or a piling up above, the level of the surrounding waters; hence, we have the depression amidship and the bow and stern waves. Mr. Froude estimates that the frictional resistance in a well formed ship, 160 feet long, from and up to a speed of six and ten knots, is eighty or ninety per cent. of the total resistance. He instances another case, in which the wave-making resistance of a ship at thirteen knots was only seventeen per cent. of the whole; but when travelling at nineteen knots it became fully sixty per cent. of the total resistance. We therefore see what huge proportions the wave-making resistance of a ship will assume, and it challenges all the

skill of our naval architects of to-day to reduce this factor to a minimum.

Allow me a word on eddy-making resistance before passing on. It is generally agreed that in well formed ships with easy curves at the entrance and run (more especially the latter), this factor in the resistance of a ship is comparatively unimportant, and Mr. Froude estimates eight per cent. of the frictional resistance as a very liberal allowance; but its amount will of course depend on the lines of the ship, especially that of the run. No general rule can be laid down; but Mr. Froude says eddies are caused rather by blunt tails than by blunt noses.

Having taken a brief, and, of necessity, a very imperfect survey of the several items which constitute the total resistance of a ship, apart from what is usually known as the augment of resistance, let us now take them separately and investigate the conditions governing each.

I will first draw your attention to the resistance usually known as "frictional resistance." The experiments from which our deductions are drawn are those which were conducted at London in the years 1796 and 1798. I take these, rather than those of a later date, principally to show how very slow we are to grasp and adopt experimental facts.

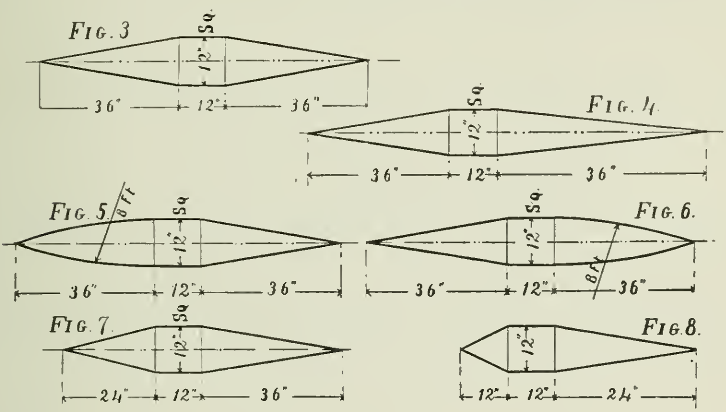
Figs. 3 to *8*, inclusive, are the forms I have taken for comparison, and for convenience the results are stated in the fractional form, thus:

$$\frac{\textit{Resistance.}}{\textit{Capacity.}}$$

The bodies were drawn through still water at velocities ranging from one to eight nautical miles per hour, and the comparisons we make will be at a velocity of five nautical miles, as those bodies that showed to advantage at this velocity maintained their superiority at the higher speeds. The value of the resistance of the several bodies will be found in the following table:

	Fig. 3.	*Fig. 4.*	*Fig. 5.*	*Fig. 6.*	*Fig. 7.*	*Fig. 8.*
Resistance, / Capacity, ...	$\frac{1}{15\cdot175}$	$\frac{1}{17\cdot895}$	$\frac{1}{17\cdot482}$	$\frac{1}{?}$	$\frac{1}{12\cdot244}$	$\frac{1}{10\cdot014}$

Figs. 3 and *4* are identical, with the exception that the after body of *Fig. 3* was taken off and replaced by another, 1 foot 6 inches longer, with the result that the mean resistance fell from $\frac{1}{15 \cdot 175}$ to $\frac{1}{17 \cdot 895}$. At first sight it appears paradoxical that by increasing the length of a body we can reduce its mean resistance. Mr. Froude, who made numerous experiments on this subject, explains this important experimental fact as follows: The portion of surface that goes first in the line of motion in experiencing resistance from the water, must in turn communicate motion to the water in the direction in which it is itself travelling, consequently the portion of the surface which succeeds the first



will be rubbing, not against stationary water, but against water partially moving in its own direction, and cannot, therefore, experience as much resistance from it. It therefore follows that the length of surface considerably affects its mean resistance, but he also showed by his experiments that there is a limit to the advantages accruing from increased length. Lengths of fifty feet, when compared with considerable shorter lengths, showed to decided advantage, but lengths over fifty feet, when compared with lengths of fifty feet showed about the same mean resistance. I presume there are a number here present who have heard of a case where a ship was lengthened and her final performance decidedly improved thereby. This, in itself, is a

practical illustration of this fact. A few years ago, the practice of lengthening ships was greatly overdone, and ofttimes the seaworthiness of the ships was jeoparded in this attempt to reduce the mean resistance.

Fig. 5 is the same as *Fig. 3*, with the exception of the slightly increased fulness at the entrance. On referring to the table, we see that the mean resistance of *Fig. 5* is very little less than that of *Fig. 4*, and is much less than that of *Fig. 3*. Now, how can we account for this superiority over *Fig. 3*? The only satisfactory answer seems to me to be that *Fig. 5* is a nearer approach to the form of least resistance for a body wholly submerged. I say advisedly, wholly submerged, for other conditions would have to be considered if the body was only immersed. For the proof of this we have only to turn to nature. The fastest fishes are so formed as to give a moderately full entrance and a very clear and fine run. The fullest section is a little forward of the middle of the length, but we know that the fish does its best when under water, not when on top, consequently this fact should be kept in mind, when the fish is compared with a ship. *Fig. 6* for speeds up to seven knots showed results about equal to those of *Fig. 3*, but for velocities above this the mean resistance of *Fig. 6* rose considerably above those of *Fig. 3*, which is what one would be led to expect after the results of *Fig. 4*, and is another illustration of the necessity of having a clear run. The increased resistance of *Fig. 6* at the high velocities is no doubt due to eddies caused by the abrupt termination of the after body. In *Figs. 7* and *8* there is a decided increase in the resistance, caused, of course, by the change in the proportion of the forebody, and due principally to the abrupt change of motion at the junction of the fore and middle body. I can imagine a considerable wake following on each side, caused by the waters eddying round the forepart of the middle body, which would mean a virtual increase in the capacity of the body, and I think we shall be safe in concluding that the principal cause of the difference in the resistance of the several bodies is the abruptness in the change of flow. Had the bodies been moderately rounded off, to conform more nearly

to the shape of a ship, there would still have been a difference in their several resistances, but not so great a difference as is here shown.

Summing up the foregoing remarks, it seems: That frictional resistance depends upon the area of the immersed surface of a ship, its degree of roughness, its length, and varies nearly with the square of the speed. It is not sensibly affected by the form or proportion of the ship, unless the form differs widely from the usually accepted ship shaped body; and for moderate speeds this element of resistance occupies by far the most important position, rising in some instances as high as seventy and eighty per cent. of the total resistance. By moderate speeds we mean those speeds most suited for the dimensions of the ship under consideration.

Wave-making Resistance.—This, as before stated, will depend on the velocity, the form of the bow and stern, and the breadth of the ship relatively to her length. It is obvious on reflection that the length as well as the form of entrance and run must greatly influence both bow and stern waves. During each interval occupied by a ship in advancing through a distance equal to the length of her entrances, the sets of particles then contiguous thereto undergo accelerations which lead to the production of the bow wave. This interval of time depends upon the ratio of the length of entrance to the speed of the ship. Similar importance attaches to the ratio between the length of run and the speed. Hence, for every speed there is a certain length of entrance and run, below which it is not advisable to go if the wave-making resistance is to be kept at a minimum.

One eminent authority states: "If the lengths of entrance and run are not suitably adjusted to the maximum speed of the ship, the waves which are formed, or a certain portion of them, diverge from her path, carrying off into still water the energy impressed upon them. The ship has, therefore, to be continually creating new waves, and, when the speed of a ship exceeds that of the waves which her entrance and run naturally tend to form, other series of waves makes its appearance, even more important than the diverging

waves. They have a length proportional to the speed of the ship, and actually keep pace with her."

It being universally admitted that for every vessel there is a speed beyond which increase of speed is obtained only by an enormous expenditure of power, let us now see what are the usually accepted proportions of length of entrance and run to the velocity. Mr. Scott Russell gives us in his *Naval Architecture* :

$$L_1 = 0{\cdot}562 \times V^2$$

$$L_2 = 0{\cdot}375 \times V^2 = \tfrac{2}{3} L_1$$

where L_1 = length of entrance, V the maximum velocity in knots per hour, and L_2 the length of run.

With these lengths Mr. Scott Russell considered there might be associated any required length of middle-body the additional resistance for the assigned speed being chiefly due to friction on the enlarged immersed surface.

Many successful ships have been built on the foregoing proportions, and in cases where the entrance has been smaller the results have been equally good; but ships having a smaller proportion of run have not been a success.

A great number of very successful ships have been built upon a modification of the foregoing rule, in which the length of entrance and run are equal:

$$L_1 + L_2 = 0{\cdot}937\ V^2$$

whence

$$V^2 = 1{\cdot}067\,(L_1 + L_2)$$

and

$$V = 1{\cdot}03\sqrt{L_1 + L_2}$$

nearly.

Having now satisfied ourselves that there is a suitable length for any given speed, let us see what are the conditions governing the breadth of the ship and the shape of the entrance and run. That is to say, what are the most suitable lines, a full easy curve as we see adopted on our Atlantic liners, or a hollow curve as usually seen on our high-speed war ships; and, if there is a reason why the difference should exist, what is that reason?

The following table of particulars relating to several ships, will furnish the data for our consideration of the question.

Ships.	Length.	Breadth.	Mean Draft.	Displacement.	Length. / Breadth.	Coëf. Fineness.	I. H. P.	Full Speed.	I. H. P. per Ton of Displacement for 10 Knots.	Remarks.
	feet.	*feet.*	*feet.*							
Livadia,	235	153	7½	4,400	1·537	·571	12,350	15·725	·477	3 screws.
Iris,	300	46	18	3,290	6·521	·463	7,500	18·	·304	
Victoria and Albert,	300	40¼	14	2,000	7·45	·4115	3,200	17·	·300	
Charles Quint,	315	33½	14 5-6	2,480	9·4	·554	2,400	16·	·202	
Edgar,	360	60	23½	7,350	6·	·506	12,961	20·97	·136	
Blenheim,	375	65	25¾	9,000	5·77	·502	21,600	21·	·156	Trial in shallow water.
City of New York,	525	63¼	25	10,500	8·3	·443	20,000	20½	—	Approximate.
U. S. New York,	380	66¼	23 10¾	8,480	5·91	·509	17,000	21·	—	
Columbia,	—	—	—	—	—	—	—	—	—	
Teutonic,	582	57 ft. 6 in	—	—	—	—	—	—	—	
Torpedo Boat,	137	·13¾	4	86	9·9	·4	1,203	21·	1·37	

Several of the speed curves have been plotted from data obtained from *London Engineering*.

Let us first see how the lengths of these ships compare with the combined lengths of entrance and run necessary to satisfy the last rule:

	Speed.	Length.	$L_1 + L_2 = 0{\cdot}937\ V^2$
		feet.	
Livadia,	15·725	235	231·69
Iris,	18·	300	303·58
Victoria and Albert,	17·	·300	270·75
Charles Quint,	16·	315	230·5
Edgar,	20·97	360	413·2
Blenheim,	21·	345	413·
City of New York,	20·5	525	393·7
Torpedo boat,	21·	137	413·

On looking at the *Livadia*, we see she has a length of 235 feet, displacement of 4,400 tons and a coëfficient of fineness of

·571, all very reasonable dimensions, and the length seems specially adapted for her speed, but when we look at the other dimensions we find most astonishing proportions, viz: a draft seven and one-half feet and a ratio of length to breadth 1·537. Taking seven knots as a reasonable velocity, and one

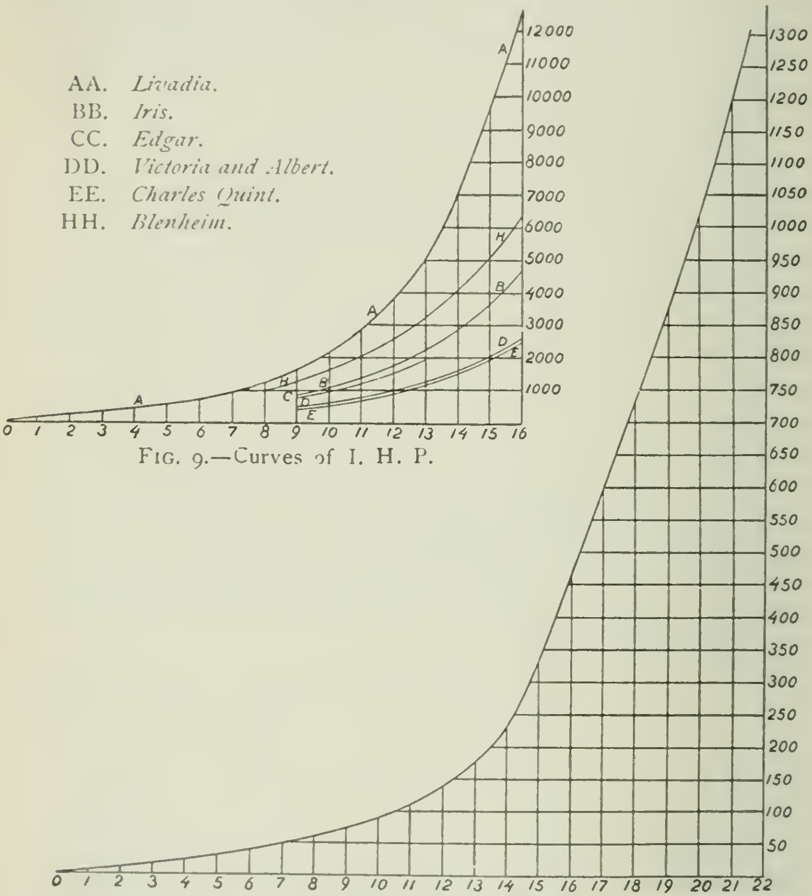


FIG. 9.—Curves of I. H. P.

FIG. 10.—Curve of I. H. P. for torpedo boat.

at which the frictional resistance is normal, we find that at ten knots that resistance is approximately as the square, but is rapidly rising, until at thirteen knots it is approximately as the cube. It is unnecessary to comment on the great proportionate expenditure of power as compared with the other

vessels, but it should be noted that her displacement, being greater than that of the other ships, somewhat favors her in the comparison of the ratio of horse-power to displacement; but the difference will be found to be considerable on referring to the column containing the results of indicated horse-power per ton of displacement for ten knots. The question naturally arises, what is the cause of this abnormally high expenditure of power? And could the proportions of the ship have been so modified as to give more satisfactory results? The answer to these questions is, that on the same displacement the ratio of length to breadth could have been considerably increased by increasing the mean draft, and much more satisfactory results obtained. What the draft or the ratio of length to breadth should have been, we are not yet in a position to state; but the lesson taught is, that if the necessity arises, in vessels of moderate speed and a given length and displacement, it is possible to exchange the ordinary form of midship section, for a very broad, shallow section of equal area, and, by favoring a considerable fineness in the buttock and bow-lines, to obtain the given speed with from thirty to fifty per cent. more power than would be required for ships of ordinary form. The proof of this we have in the stern-wheelers, built by Yarrow & Co., London, and also in the numerous shallow steamers navigating the waters of the many rivers of this country. But there is decidedly a ratio of length to breadth below which it would not be advisable to go. In the case of the *Livadia*, there was no doubt a considerable loss of power due to the abruptness of the lateral deflection of the stream lines, which would result in forming excessive waves and wake.

The *Iris* in her day was considered an exceptional ship, and her dimensions contrast most favorably with ships of more modern construction. There is one thing, however, that we should remember when making comparisons between ships of a comparatively early date and those of to-day, namely, that the machinery for these older ships was designed for much lower pressures and would consequently be much heavier and more clumsy than those of

to-day. The engines of the *Iris*, at full speed, ran at about ninety revolutions per minute, and the power necessary to overcome the constant friction of the machinery at this speed would be about from eight to ten per cent. of the total indicated horse-power; whilst at from nine to ten knots it would require about thirty per cent. of the indicated horse-power. This would also apply to the *Victoria and Albert*, she being fitted with the old oscillating style of engine, running at about thirty revolutions. The augment of resistance in the *Victoria and Albert* would also be increased, owing to the extra friction caused by the flow of the paddle race past the sides. All these points should, therefore, be considered when making comparisons. Looking now at the results obtained by the *Edgar* and the *Blenheim*, we are forced to the conlusion that they are real and marvellous triumphs of modern skill. The *Edgar* is carrying one ton on about 1·76 indicated horse-power, at about twenty-one knots. The *Blenheim*, under most unfavorable conditions, is carrying one ton on 2·4 indicated horse-power at twenty-one knots. The liner *New York* carries one ton on 1·9 indicated horse-power, and at a speed of 20·5 knots, a performance about the same as that of the *Blenheim*, and very much inferior to that of the *Edgar*. The question that naturally arises in one's mind is, if on the dimensions of the *Edgar* we can carry one ton with smaller expenditure of power than we can on the dimensions of the liner *New York*, why should we resort to the longer form? And why do we hear so much about ships of 600, 800 and 1,000 feet long, to cross the Atlantic in four days, if the results can be obtained with ships of more moderate dimensions, having a smaller proportion of length to breadth, and by employing much finer extremities, such as the hollow water lines which usually obtain in high-speed war cruisers and torpedo catchers.

In comparatively smooth water, when going at full speed, the liner *New York* rolled considerably. Now it seems to me that in a ship of more moderate dimensions the period and amplitude of the oscillation could be greatly reduced; and in a passenger ship this point should have some weight.

Ships, like the *Campania* and *Lucania*, which have a length more than ten times their depth, vibrate considerably.

The cruiser *New York* developed a speed of twenty-one knots on an indicated horse-power of 17,000, and a displacement of 8,480 tons. This is equivalent to 2·12 indicated horse-power per ton of weight at twenty-one knots, and on referring to her photographs, taken when on her full speed run, you will see by the proportions of her bow and stern wave, that she had about reached the limit of her speed; this is also discernible in the very steep rise of her speed curve at this speed. If, on the dimensions of the cruiser *New York*, we can obtain such excellent results, should we not be justified in expecting as good results from the liner *New York* with length, 413 feet on water line, 70 feet extreme breadth and 25 feet mean draft of water, or with mean draft increased to 28 feet and the beam correspondingly reduced to suit.

The results obtained from the torpedo boat show what a severe penalty we pay in order to obtain high velocities from exceptionally short bodies. At twenty-one knots we absorb no less than fourteen indicated horse-power per ton of displacement.

BOOK NOTICE.

Lecture Notes on Theoretical Chemistry. By Ferdinand G. Weichmann, Ph.D. First edition. New York: John Wiley & Sons. 1893.

This volume is an elementary treatment of the subjects embraced in what is covered by theoretical chemistry, as the term is at present understood. The treatment appears to us to be unusually well adapted for the comprehension of students of chemistry, and the lecture notes will probably be warmly welcomed by instructors in the science. The author is an instructor in chemical physics at Columbia College, and the lecture notes have evidently been evolved into book form on account of the need felt for such a comprehensive treatment of the subject. The introduction of practical problems in connection with each chapter adds substantially to its value for the class of readers for whom the book has been prepared, and the elaborate bibliographical list at the close of the volume will serve as an excellent guide for the ambitious student who may desire to extend his studies of the subject.

W.

Franklin Institute.

[*Proceedings of the Stated meeting, held Wednesday, March 21, 1894.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 21, 1894.

JOSEPH M. WILSON, President, in the chair.

Present, seventy members and five visitors.

Additions to membership since last report, twenty-one.

The Secretary presented a communication from Mr. George F. Kunz, Secretary of a Joint Committee on Coinage of the National Sculpture Society and the Numismatic and the Archæological Society, requesting the appointment by the Franklin Institute of a committee to represent it in the Joint Committee. The objects of this committee, briefly stated, are to endeavor to bring about an improvement in the design of our national coins in the interest of good art, and to secure the application of the metric system to the coinage.

It was the sense of the meeting that the objects named in the communication were not directly germane to the purposes of the Institute, and accordingly no action was taken.

Mr. E. P. Holly, of Providence, R. I., presented a paper describing a "Gravity Return System," of his invention, for automatically returning water of condensation to steam generators, where the latter are situated above the level of the attachments to be drained. The author illustrated his paper by the exhibition of a number of diagrams, showing various modes in which his invention could advantageously be applied in practice.

The paper was freely discussed by Mr. Walter H. Kerr, Mr. Spencer Fullerton, the author and others.

The Secretary exhibited, with the aid of the lantern, views of plans for underground and elevated railways at present under consideration, or in course of execution, in the cities of New York and Boston.

The Secretary made allusion to the proposition of Mr. F. L. Stewart, of Murraysville, Pa., for utilizing the corn cane as a source of sugar, and gave a brief statement of the facts observed by him and upon which he bases the claim that the corn cane may be utilized with profit as a sugar plant.

The Secretary stated that the publications of Mr. Stewart on this subject had attracted an unusual amount of attention because of their bearing on one of the greatest of our industries, and that, in order to be prepared to answer several inquiries he had received in relation to them, he had requested, and obtained, the opinion of an expert occupying a responsible official position under the Government, and who was in all respects qualified to judge of the value of Mr. Stewart's facts and propositions.

The Secretary regretted to have to state that, in this expert's opinion, the facts on which Mr. Stewart's propositions are based are misleading, and the prospects for utilizing the corn stalk as a commercial source of sugar, too unpromising to be worthy of serious consideration.

Adjourned.

WM. H. WAHL, *Secretary.*

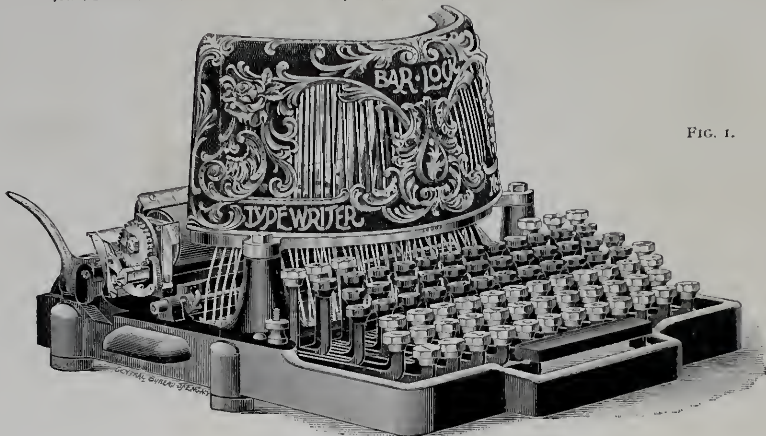

BAR·LOCK
TYPEWRITER
CENTRAL BUREAU OF ENG'G

FIG. 1.

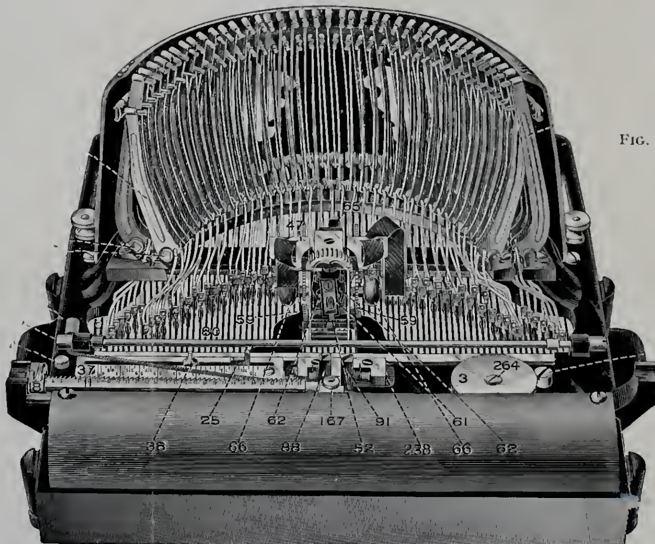

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FIG. 3.

JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXXXVII. MAY, 1894. No. 5

THE BAR-LOCK TYPEWRITER.

[*Being the report of the Institute by its Committee on Science and the Arts on Improvements in Typewriting Machines invented by Charles Spiro.*]

The Committee on Science and the Arts received from the inventor, Mr. Charles Spiro, the accompanying letter setting forth his claims to merit in the design, construction and operative features of the bar-lock typewriter. As will be perceived from the report which follows, the committee charged with the investigation of the subject, has considered and passed judgment on these claims *seriatim:*

NEW YORK, June 2, 1893.

To the Committee on Science and the Arts of the Franklin Institute, Philadelphia, Pa.:

GENTLEMEN:—In bringing my invention of the bar-lock typewriter before you for your consideration, I desire to state as briefly and concisely as possible the advantages possessed by this machine. My idea is that the best typewriter is that one which enables the operator to produce the most work of the finest quality, in the shortest time, with the least physical effort.

It has, therefore, been my endeavor to accomplish these results in as simple a manner as possible, and at the same time to make its movements, where possible, automatic.

Visible Writing.—With this object in view, the machine was so designed that the writing should be in full sight of the operator, as if he or she were using a pen, thus obviating the necessity of wasting time in lifting the paper carriage or pulling forward the platen to examine the work done. Having gained this advantage, it becomes very simple to make alterations or to execute tabular work thereon. Visible typewriting increases the output of the machine, as three words can be written in the space of time required to lift the paper carriage, and on an average an expert operator will lift the paper carriage once in every five lines.

Automatic Line Spacing.—The next improvement was to make one movement suffice for returning the paper carriage to the right and turning forward the paper, ready for a fresh line. To this must be added the light paper carriage, allowing of a very rapid movement. On a careful test it has been found that a new line is started every thirteen words. On the majority of typewriters, the action of starting a new line occupies a space of time equal to *four* words of writing On the bar-lock the time occupied is equal to that of writing *two* words. The operator is saved the one entire action.

Automatic Ribbon Reversing Gear—On all typewriters using ink ribbons, it is necessary when the ribbon has been fully unwound from the spool for the operator to reverse the driving gear. On the bar-lock, when the ribbon has reached either end, it automatically reverses, thus saving the operator any effort in this direction, and also avoiding the fear of a letter being spoiled through the operator forgetting to reverse the ink ribbon, which is a matter of common occurrence on other typewriters, as no warning is given by the machine that the end of the ribbon has been reached.

Automatic Platen Backward Release.—The operator does not have to lift up the driving pawl used in driving the paper forward, when it is necessary to turn the paper back, as on other machines. The backward movement of the platen of the bar-lock throws the platen automatically out of mesh with the ratchet wheel.

Automatic Keyboard Lock.—Many operators are troubled through not noticing the ringing of the bell, and thus spoil the appearance of their work by writing after the carriage has reached the end of the line. By this device the operator can cause the keyboard to be locked at any desired number of letters after the ringing of the bell, thus preventing the keys being depressed to print. This lock is so designed that the keys are not locked rigidly, but are allowed to descend a short distance, avoiding any shock to the operator's fingers. By the simple turning of a screw this device can be thrown out of gear, if the operator prefers the machine without it.

Automatic Double Bell Alarm.—This is of use where an operator is writing two columns of any matter, and wishes an alarm at both columns. It can also be used at the end of the line for a double bell alarm, in the event of the first bell being unnoticed.

Device for Writing on Ruled Lines.—It is very often necessary to fill in a date or numerals on a given line on the sheet of paper. This necessitates on other typewriters, considerable waste of time in pulling the paper by the

hand until it reaches the desired spot. By my invention, it is only necessary to depress a small lever, and the paper platen can then be turned in any direction and to any position. Thus an interlineation can be made, and invoices can be made out on ordinary ruled paper, or blank forms filled in, without loss of time.

Margin Devices.—I would also draw attention to the simplicity and rigidity with which the left or right hand margin can be set at any desired spot.

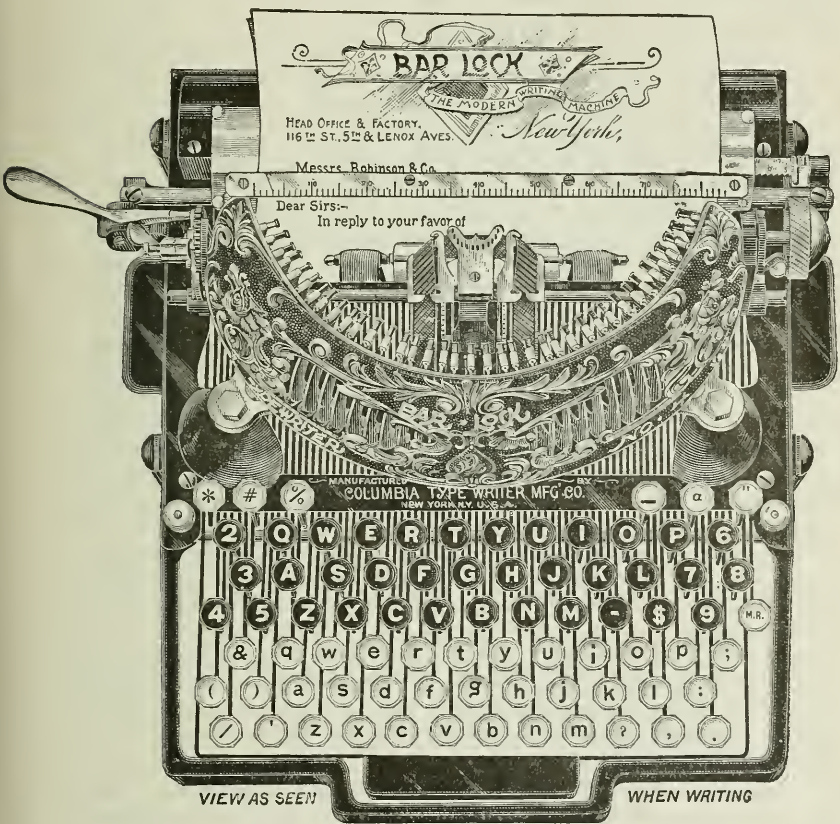

FIG. 2.

Automatic Margin Release.—The margin stop on this machine is so contrived that upon the depression of a key the margin set for is instantly released, enabling the operator to insert the initials *Q* and *A*, the names of witnesses, etc., or to write marginal notes, at the left of the marginal ruling originally set for. When the marginal note is completed, the stop automatically recovers its first setting.

Typebar Lock.—The great problem of all manufacturers of typewriters is to devise a typebar-bearing or a lock which will insure the printing of the type in

alignment after considerable wear. There have been many attempts to make a lock for the typebars, some being designed to guide the typebars by means of a groove, and others making use of a locking aperture over the printing point to receive the type. The disadvantage of both these methods was the weakening of the stroke of the typebar, caused by the friction, and also that the alignment depended on the lock *solely* and the type was literally *forced* into the lock. With the bar-lock, the lock is simply to *maintain* the alignment and is not to *force* the alignment; that is, each typebar is of such a character that it has a joint sufficiently rigid to insure the letters printing upon a straight line when the machine is new; but instead of depending upon this joint after the machine is old, as is the case in the majority of typewriters, the lock is placed near the printing point, which receives the typebar at the moment of contact with the paper and prevents any side play. This lock consists simply of a semi-circle of conical phosphor-bronze pins about three-sixteenths of an inch in height. The only friction therefore is the friction of two small pins against a flat bar, and this does not occur until after the bar has attained its fullest momentum, and hence does not in any way weaken the stroke for manifolding or retard the quick recoil of the typebar from the platen.

Typebar Hangers.—It being my object to make the most durable typewriter possible, I have placed not only a lock at the printing point, but have made my typebar bearings or hangers adjustable. To do this, I have designed an adjustable ball and cup bearing. My claims of superiority, as compared with the ordinary cone bearings, are that the ball and cups have a coincidence of bearing surface at every angle, so that when the adjusting screws draw the forks of the hanger together, it makes no difference whether the forks are parallel or not; hence the taking up of the hanger for wear does not affect the typebar.

Other Features.—In addition to the leading features peculiar to the bar-lock which I have enumerated, I have also included in the machine many other advantages, some of which are possessed by other typewriters, though in a different form.

Among these, I may state that the paper platens are *instantly* removable and interchangeable, so that an extra hard platen may be inserted where a large number of manifold copies are required.

The ink ribbon spools are also interchangeable and reversible, so that the whole width of the ribbon can be utilized.

For obtaining a uniform margin on many sheets of paper there is an adjustable margin guide, and by depressing a small lever flimsy paper can instantly be withdrawn from the carriage without fear of injury.

The carriage release for moving the carriage to the left is instantaneous, and the carriage stops "dead" and does not jump several teeth as on other machines.

I have also a special feed for printing envelopes quickly without rolling them around the platen.

My key-levers are of steel and in one piece. The typebars are of resilient steel, and if two keys are accidentally depressed at one time, neither letter prints and the typebars are uninjured.

The arrangement of the typebars is such that the whole of the type can be cleaned in five seconds. I use a standard keyboard of *seventy-eight* keys, arranged in duplicate of capital and small letters. The touch of the machine is light and easy, and the action more nearly noiseless than ever before attained. * * * * * * * * *

I am, gentlemen, Yours respectfully,

CHARLES SPIRO.

REPORT.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 30, 1893.

The Franklin Institute of the State of Pennsylvania for the promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the "Bar-lock typewriter," finds as follows:

This machine is fully described and illustrated in the following letters-patent, copies of which are annexed, viz:

No. 322,495 Jnue 21, 1885, granted to C. Spiro.
No. 322,989, July 28, 1885, granted to C. Spiro.
No. 331,337, December 1, 1885, granted to C. Spiro.
No. 339,078, March 30, 1886, granted to C. Spiro.
No. 344,143, June 22, 1886, granted to C. Spiro.
No. 352,160, November 9, 1886, granted to C. Spiro.
No. 355,418, January 4, 1887, granted to C. Spiro.
No. 395,799, January 8, 1889, granted to C. Spiro.
No. 400,265, March 26, 1889, granted to C. Spiro.
No. 400,716, April 2, 1889, granted to C. Spiro.
No. 410,743, September 10, 1889, granted to C. Spiro.
No. 422,042, February 25, 1890, granted to C. Spiro.
No. 435,775, September 2, 1890, granted to C. Spiro.
No. 438,901, October 21, 1890, granted to C. Spiro.
No. 445,333, January 27, 1891, granted to C. Spiro.
No. 447,438, March 3, 1891, granted to C. Spiro.
No. 454,080, June 16, 1891, granted to C. Spiro.
No. 475,623, March 24, 1892, granted to C. Spiro.
No. 476,093, June 14, 1892, granted to C. Spiro.
No. 481,377, August 23, 1892, granted to C. Spiro.

It is a full keyboard typebar machine, with upright typebars printing on top of the platen in full view of the operator, arranged in two decks so that the whole seventy-eight typebars occupy only about one-third of a circle.

The details of construction of the machine will be

brought out in the discussion of the special "points of merit" claimed for it, in which it will be stated whether, and to what extent the same or similar "points of merit" exist in other machines within the knowledge of the committee conducting the investigation; the statement that any of these is found in one or more other machines not implying that the same other machine is always meant, as the contrary is the case.

(1) *Visible Writing.*—The writing in this machine is entirely visible for the last two lines of the work, including the last letter struck. Other machines within the knowledge of the committee have this point with equal perfection, and some others more or less proximately.

(2) *Automatic Line Spacing*, or the partial revolution of the platen for a new line by the act of returning it for the beginning of a line. This point is found in other machines.

(3) *Automatic Ribbon Reversing Gear.*—When the ribbon has run to its end, it is automatically reversed, so that the operator is not called upon to pay any attention to its position, and is not liable to continue writing after the ribbon feed has ceased, wasting time and spoiling work.

This point is found in no other machine and is of importance. This, however, gives no advantage over those which print directly from the type without the intervention of the ribbon.

(4) *Automatic Platen Backward Release.*—The platen is turned backward by simply turning the knob on its end without other action. This point, which is often very convenient, is found on no other machine.

(5) *Automatic Keyboard Lock.*—At any given point at which it is desired to end the line of writing the keys may be so locked that the types will not print, not rigidly locked, but so that the typebar will move down part way, without shock to the finger of the operator, or to the machine. The feature of locking the key at a given point of the line is found in one other machine, but the allowance of partial movement, without writing, in no other.

(6) *Automatic Double Bell Alarm.*—This machine has two bell alarms, one of which can be set at any point on the line,

and the other near the end, so that two alarms can be given for two separate columns on the same page, or a double alarm at the end of the line, so as to insure the attention of the operator. This point is found in no other machine, and may occasionally be of advantage.

(7) *Device for Writing on Ruled Lines.*—The platen feed may be thrown out of gear by a single movement of a lever, and the platen can be moved to write on previously ruled lines. This point is found on other machines.

(8) *Margin Devices.* -For setting a margin on either end or both ends of the line. This point is found in other machines.

(9) *Automatic Margin Release.*—By the touch of a key the left hand margin stop may be thrown out of action, enabling the extension of the line to the side of the page or the making of marginal notes. This point, as far as relates to the actual doing of the thing, is found in two other machines, but in none with the facility with which it is done in this machine.

(10) *Typebar Lock.*—The typebar at the point of making its stroke, is locked in position so that the proper position of the letter on the line is assured. This point is found in other machines.

(11) *Typebar Hangers.*—The typebars move in adjustable ball bearings, in which wear can be accurately taken up. This point is not found in any other machine.

These are the principal features of special excellence over other machines claimed for this one, and in addition, the inventor names several other "advantages" which, as he correctly states, are "possessed by other typewriters, though in different form," and which are, therefore, not necessary to be enumerated here.

The relative advantages of the partial keyboard, with shift or shifts, and the full keyboard, is a matter depending upon the personal aptitude of the operator, and is a subject upon which we do not feel called upon to express an opinion; but, disregarding this question, and comparing this machine with other writing machines, we find that although some machines possess capabilities not possessed by this

one, it presents an exceedingly advantageous combination of them and has some points of merit peculiar to itself. It has a light, elastic touch and a very positive movement of its platen escapement. It has a long typebar, and is, therefore, a good manifolder.

The Institute, therefore, recommends the award of the John Scott Legacy Premium and Medal, to Charles Spiro, of New York, for his "Improvement in Typewriters."

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, December 6, 1893.

JOSEPH M. WILSON, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by

H. R. HEYL,
Chairman of the Committee on Science and the Arts.

Award confirmed by the Board of Directors of City Trusts, 1894.

ON GAS BURNERS, GAS PRESSURE REGULATORS AND GOVERNOR BURNERS, GAS GLOBES AND GLOBE HOLDERS, AND GAS FIXTURES.

BY WM. PAUL GERHARD, C.E.,
Consulting Engineer for Sanitary Works, New York City.

In the following pages I propose to discuss the chief means for obtaining a good and satisfactory illumination by gaslight. It is to be assumed:

(*a*) That the gas supplied to the consumer is properly purified at the gas works, and that in quality it is of the requisite and sufficient candle-power:

(*b*) That the gas piping in the building has been done in a first-class manner; that pipes and fittings of proper material and of ample size have been used; that these pipes and fittings have been put together in a workmanlike manner and are tightly jointed; that the distributing pipes have been properly run, with sufficient grade and with good fastenings and supports; that all gas outlets have been securely

strapped; and that the piping has stood a severe pressure test, and has no leaks or imperfections:

(*c*) That the gas company has run a service of ample size into the premises, and has set a gas meter of sufficient capacity to supply ail lights or burners likely to be kept burning at one time.

Under such conditions the factors upon which the illumination depends are the gas burners, the pressure regulators, the globes and globe holders, and the gas fixtures.

Briefly stated, the essential steps which gas consumers desiring good illumination should take, are:

(1) To select and use the best quality of gas burners, for these will not only give a better light, but they will burn less gas in proportion to the candle-power developed than poor burners, or, to put it in other words, they will produce a higher candle-power per unit of gas consumed.

(2) To regulate the pressure with which the gas issues at the burner, which may be accomplished either by the use of gas pressure regulators on the main house pipes for gas, or by using volumetric or governor burners at the gas fixtures.

(3) To regulate the air supply to the flame which is accomplished by the use of suitably shaped and suitably placed gas globes, and in the case of argand burners by the use of well proportioned glass chimneys.

(4) By selecting well designed and well constructed gas fixtures and judiciously placing same in the apartments to be lighted.

According to an elaborate report made by the London Gas Referees in 1870, a serious waste of gas occurs, owing to the great number of bad burners in general use. Consumers may, by using good instead of poor burners, obtain from thirty to fifty per cent. more light without any increase in the gas bills. From this it is evident that gas may be used wastefully or economically, this depending largely on the selection of the burners. Burners suitable for ordinary coal gas are not adapted for gas of high candle-power, and *vice versa.* Unfortunately, the proper methods of burning gas are little understood, not so

much owing to want of popular information on the subject, as on account of the general indifference of the gas consuming public as well as of the gas companies. Gas consumers are, as a rule, very slow in the adoption of progressive methods or appliances in domestic gas lighting, and the gas companies, with a few commendable exceptions, have not in the past made the slightest efforts in the interest of the consumers, by explaining in a lucid manner the problem of how to burn gas economically, and how a maximum efficiency of light, combined with perfect and complete combustion, may be obtained from the burning of a cubic foot of gas.

Much remains to be accomplished in this direction, many widely existing fallacies regarding gas lighting have to be fought and removed, and in their place a correct knowledge of the principles of gas illumination should be disseminated. In by far too many cases the existing conditions, such as too small pipes, meters of insufficient capacity, excess of pressure, bad burners, ill-shaped globes, cumbersome globe holders and defective gas fixtures, preclude any chances of obtaining a successful illumination.

I cannot here go into a consideration of the nature of the gas flame or into the theory of combustion, and will simply state as a general axiom that gas *should be burnt at a low pressure.* The most favorable pressure varies slightly with the quality, candle-power and specific gravity of the manufactured gas, but may be taken on an average as five-tenths inches of water pressure at the burner. An excessive high pressure of gas has a tendency to reduce the illuminating power of the gas flame and causes the roaring or singing of a flame, the flickering of the light, the cracking of glass globes and a waste of gas.

On the other hand, if the pressure is too low, the flame is apt to smoke, becomes dull and reddish in appearance and vitiates the air.

I.—GAS BURNERS.

A gas burner has been defined as the point at which illuminating gas issues from the service pipe to be ignited

for the purpose of giving light (or in some cases heat). All burners are composed of two parts, the body and the tip of the burner.

Early in the history of gas lighting we find the energies of able inventors devoted to the improvement of the originally crude devices serving as gas burners, and it is both interesting and instructive to follow the gradual development of the better class of burners. A fresh impetus was given to the gas burner industry by the introduction of the electric light. This compelled gas companies to devote attention to the available better gas appliances for street illumination, and also caused consumers to make inquiries about the details of properly constructed gas burners for interior lighting. At the present day the simplest as well as the most scientifically and accurately constructed gas burners are available, and new improvements are constantly being made.

Broadly speaking, we may distinguish between the following *types of gas burners*, viz :

(*a*) Single jet burners.
(*b*) Flat-flame burners.
(*c*) Round-flame burners.
(*d*) Multiple burners.
(*e*) Regenerative burners.
(*f*) Incandescent burners.

Of all gas burners the *single jet burner* is the simplest and crudest, consisting of a plain body and tip generally combined, having only one small round aperture for gas. These burners are used only to a limited extent where a very small flame is required, and hence we may dismiss them with these few words.

The second and third types of burners, viz., the flat-flame and the round-flame burners, are those with which we are chiefly concerned in dwelling house illumination, and of these two types again, the bulk of burners used belongs to the flat-flame type.

All *flat-flame burners*, as the name implies, spread their flame in a thin, broad sheet. It is usual to distinguish two

kinds of flat-flame burners, viz., the bats-wing, or slit-union burner, and the union-jet, or fish-tail burner.

The batswing burner has a hemispherical tip, with a narrow vertical slit, from which the gas issues in a thin and broad sheet, whereas the union-jet, originally invented by James Milne, of Edinburgh, consists of a flat and sometimes of a slightly depressed, or concave tip, with two small holes drilled under a certain angle to each other, from which two jets of equal size issue, and impinging upon one another produce a flat flame.

Flat-flame burners do not require the use of a chimney to prevent the smoking of the flame, but as a rule, the gas flame is sheltered against draught by surrounding it with a glass globe.

As originally constructed the two burners produced flames widely differing in character, the batswing burner giving a flame of great width and little height, while the fish-tail burner produced a flame considerably narrower and longer.

On account of its great width, the flame of an ordinary batswing burner is easily affected by even slight currents of air, which cause the flame to smoke, and the protection which a glass globe affords to the flame cannot be so readily applied to the common batswing burner, because the slightest lateral deviation of the broad flame often causes the cracking of the glass globe. This is one reason why ordinary union-jet burners are so commonly used on gas fixtures with glass globes, although the batswing burner is slightly preferable, as regards development of light.

An early step in the improvement of flat-flame burners consisted in simple and crude devices intended to reduce the velocity with which gas issues at the burner orifice, owing to the gas pressure, experiments having established the fact that a greater degree of illumination could be obtained by burning gas at a low pressure. These devices consisted in introducing some mechanical obstruction, such as wire gauze, or cotton, or wool, or a mica disc, or a regulating screw, into the body of the burner. Owing to the fact that coal gas is not always well purified, all devices

which serve to constrict the lower part of the burner, are very liable to stop up with tarry matters carried in suspension in the gas, which become condensed and are deposited in the wire gauze or in the wool. After some use, such "check burners," as they are sometimes called, generally become unfit, or at least produce a very ragged and uneven flame, owing to the material in the body of the burner becoming more obstructed in some parts than in others.

The first valuable improvement in gas burners consisted in the choice of a more suitable material for the tip or head of the burner. The old burners, which are, unfortunately, still much in use at the present day, were usually made entirely in one piece, either of iron or of brass. Movable tips were introduced later on, and were inserted into the metal body of the burner, but at first these tips were still made of iron. This material is objectionable for two reasons, viz: first, the burner orifices in union-jet and in batswing burners become rapidly choked by the corrosion of the metal. Such obstructions by rust may, it is true, be removed from time to time with burner cleaners, sold in hardware stores or obtainable from the gas companies, those for union-jet burners being in shape of a small awl, while those for slit burners consist of thin strips of sheet brass or steel, fastened to a suitable handle. The average householder rarely bothers himself with such matters; but even where these burner cleaners are used, the inevitable result of their too frequent or careless use will be that the burners quickly become injured or destroyed. The nickel plating of the iron burner tips obviates to some extent the corrosion of the burner orifice, and quite recently a non-corrosive metal gas tip has been put on the market, for which the advantage is claimed that it does not chip or crack, as lava tips sometimes do.

A second and more important objection against brass or iron burner tips is that metal being a good conductor, abstracts much heat from the burner tip, and thereby reduces the temperature of the flame, causing some loss in the degree of illumination.

Therefore, a great step forward was made by the intro-

duction of non-metallic, non-corrosive and non-conducting substances for burner tips. The material most commonly used is lava, but this is brittle and cracks easily, and various gas burner manufacturers employ other materials, such as porcelain, or steatite (a sort of soapstone of very fine grain which burnt in a kiln becomes hard and incorrodible, and is easily polished) or "adamas," a compound artificial material of a mixture of various earths or minerals, or some sort of "enamel."

Sugg's burners have steatite tips, Bray's burners enamel, and Leoni's burners adamas tips; and all modern improved flat-flame and round-flame burners have tips made of one or the other of these materials, which are practically everlasting and not susceptible of oxidation.

Further improvements made relate to the shape of the tip and of the body of the burner. In some gas burners, for instance, the body is suitably enlarged to form a sort of expansion chamber wherein the velocity of gas as it issues from the pipe is, to some extent, checked.

The batswing burner was improved by making the interior of the top of the burner hollow. The slit thereby becomes of equal depth throughout. Sugg also improved the batswing burner by cutting the slit with a circular saw, which has a favorable effect upon the shape of the flame. The advantage is thereby gained that gas issues more uniformly at all the points of the tip, and the shape of the flame thereby becomes improved, becoming less broad and somewhat taller.

A further improvement of the batswing burner was made by Wm. Sugg, who applied a rim-like projection to the outside of the burner below the slit, a so-called "table-top," the object of which was to check the rush of the outer air in the immediate vicinity of the flame. Thus the flame is better protected from draughts, the shape of the flame is more evenly preserved, and all smoking is prevented.

Manufacturers of union-jet burners, in turn, were not slow in applying improvements to their type of burner. Some introduced into the body of the burner layers of muslin to check the flow of gas, others inserted plugs or wash-

ers of enamel, perforated with small apertures for the passage of gas. These apertures can be adjusted to various pressures, and the ultimate object in view is to cause the gas to issue at the burner tip at the lowest pressure consistent with proper illumination. The result is that the height of the gas flame, which in the common fish-tail or union-jet burner is excessive, becomes considerably reduced and the roaring and flickering of the light is prevented. A similar result was obtained by making the burner top slightly hollow, and the angle at which the two streams of gas meet, more obtuse.

By all these improvements the two at first quite different flames of the batswing or slit burner, and of the union-jet or fish-tail burner have been modified and gradually altered so much that in their modern most improved form the shapes of the flames of the two types, are *practically identical.*

Among the best improved flat-flame burners are those of Broenner, Leoni, Sugg, Bray and Silber. The Sugg improved hollow-top steatite slit burner, the Sugg circular slit table top steatite burner, the Bray enamel non-corrosive "regulator" fishtail and slit burners, and the Silber "Concordia" flat-flame burner, which has two small burner orifices separated by an intervening wedge-shaped piece of brass, are among the best ordinary flat-flame burners obtainable in the market. These burners are all of English make, except the Broenner burners, made in Frankfort-on-the-Main, Germany. Of the latter burner eleven numbers are made, consuming from one to eight cubic feet of gas per hour. They give a more uniform light with varying gas pressures, and if judiciously selected and fitted with the "Cornelian" globes with large bottom and top opening and a shadowless glass holder, as recommended by the manufacturers, they give a good light.

I have not learned of any efforts on the part of American gas fitting manufacturers to provide improved ordinary flat-flame burners, comparable at all in efficiency with those above named.

The mill burner with screw check, the "Empire" check

burner with inside adjustable screw cylinder with slot, the "Imperial" burner with wire gauze to check the flow of gas, the Gregory mica flap burner and the ' Young America" burner with small brass diaphragm pierced by minute holes, are gas burners of American make, and being in the nature of check burners are somewhat better than the ordinary kind. I shall, however, have occasion further on, when speaking of governor burners, to mention some very excellent American flat-flame burners.

In a dwelling house of average size only a comparatively small number of burners are required, hence it will pay gas consumers to put on their fixtures the best burners, whatever their price may be. Improved gas burners are also much preferable from a sanitary point of view, because there is less contamination of the atmosphere in a house.

Regarding the size of the burners I would say, wherever a dim light only is required, as in halls, passage-ways and bathrooms, two or three foot burners, and for bedrooms three or four foot burners may be used, but for the gas fixtures in the principal rooms large burners, consuming from five to six cubic feet of gas per hour are much to be preferred, and it should be borne in mind that for bright illumination a few large burners—under low pressure—are preferable to a large number of small burners. Under all circumstances consumers should avoid making the mistake of procuring gas burners promiscuously from irresponsible agents or from peddlers and afterwards blaming the gas company for "poor light," or for exorbitant gas bills.

Before leaving the flat-flame burners, I ought to mention some *automatic safety* gas burners recently devised, the object of which is to automatically shut off the gas supply in case light is accidentally extinguished, or "blown out," or in case the gas key is inadvertently turned on. An American patented device of this kind has a wire protruding from the burner tip, and extending down to the bottom of the burner where it comes in contact with a small valve. While the burner is cold the valve is closed, cutting off the gas supply. When a light is applied to the burner the wire becomes heated, expands, lengthens and pushes the valve away from

its seat, thereby admitting the gas to the burner tip. As soon as the flame is extinguished, the wire by cooling contracts and again cuts off the gas. A similar safety regulator burner is patented by Jahn, and manufactured by Friedrich Lux, of Mannheim, Germany.

These burners would seem to be specially adapted for hotels and lodging houses where gas is often "blown out" by ignorant people, and they may prove successful in preventing suffocation, suicides, explosions and other accidents due to escaping gas.

I have devoted a great deal of space to the discussion of the ordinary flat-flame burners because, the Argand, regenerative and incandescent burners notwithstanding, they are still the consumer's favorite burners, and because the bulk of illuminating gas used for lighting purposes is at present burnt in batswing and fish-tail burners. Further mention of flat-flame burners will be made in the discussion of governor burners. I will now pass on to consider the round-flame, or so-called Argand, burners.

Argand or *round-flame burners* consist essentially of a hollow ring, connected with the gas tube and perforated on its upper surface with a series of fine holes from which the gas issues, forming an annular hollow round-flame. The Argand burner derives its name from its similarity with the Argand oil lamp, and like the latter always requires a glass chimney, properly proportioned in diameter and height, to induce a perfect combustion by increasing the air supply to the flame, and to lessen its susceptibility to side draughts. The Argand burner gives a higher candle-power per unit of gas consumed than flat-flame burners. The original burners of this type were not constructed on scientific principles, no provision having been made in them for regulating the air supply to the flame and—what is equally important—the pressure of gas, and hence these burners were liable to smoke.

We are indebted for important improvements in this direction to Mr. William Sugg, the well-known English manufacturer of improved gas-lighting appliances. In his improved Argand burner gas is delivered at a very low pres-

sure, the supply is distributed evenly throughout the entire ring of holes, the flame generated is of even and regular shape, the chimney, which is so essential to the round-flame burner, is properly proportioned in diameter and height, and the burner is made of "steatite" instead of, as formerly, of metal, which abstracts too much heat from the flame. The Sugg "London" Argand burner, with twenty-four holes, was selected by the London Gas Referees, in 1869, as the standard test burner for sixteen candle gas.

Further improvements were embodied in Sugg's "London" improved Argand governor burner, which develops a still better light from the gas consumed, and in which a regular and uniform supply of gas to the burner is insured by the use of either a steatite float or a leather diaphragm governor.

An equally excellent Argand burner, with automatic governor, is made by the Silber Light Company, of London, while of American round-flame burners I mention the "noiseless" Argand burner, made by the Gleason Manufacturing Company. All these burners are much improved by the addition of the volumetric gas governor which maintains a steady flow of gas and regulates the pressure. Of this apparatus I have occasion to speak hereafter.

The Siemens precision burner is an improved Argand burner, having a flat disc in the center of the flame, which causes same to bulge out and tends to a more perfect combustion with increased luminosity of the round-flame. This is similar in principle and construction to the metal button deflector placed over the air tube, as adopted in many of the modern improved central draft oil lamps.

Similar modifications of the Argand burner are the Grand gas lamp, the Niagara Argand burner, the Royal Argand, the Gordon-Mitchell high-power gas lamp, with inverted annular burner, forming a small regenerative Argand burner, and the Morey incandescent gas light burner.

In order to obtain increased illumination, *duplex* and *multiple* gas burners were invented. In the double, duplex, or "twin" flat-flame burner, two batswing or sometimes two

union-jet burners are placed together on the same body and set at a certain angle to each other, so that the two flames are made to combine. A somewhat greater amount of light is developed thereby than by using the two flames separately, but the light is no better than that obtained through a large single burner.

Multiple burners consist of several concentric rings of round burners, or else of a series of three, five or more flat flame burners arranged in such a manner that from whatever point they are looked at, a flat side of the flame is exposed. Bray's high-power street lamp burners belong to this class, as well as Sugg's "Walthamston" and "Taj" high-power lights. They have been gotten up and used to some extent to obtain a brighter street illumination, also for lighting stores and large halls. The street lanterns of this type are made storm-proof, so that the flame is not affected by the wind, and are provided with milk white glass at the top of the lantern for the purpose of reflecting the light downward. Multiple round-flame burners have been adopted to a limited extent in lighthouse and street illumination, such as the Wigham multiple burner and the Germania double and triple concentric Argand burners.

The "Shaw" reflector light is a regenerative multiple flat-flame burner, in which an attempt is made to superheat the gas before ignition. Halliday's "Clapton" lights are similar in principle, and in the United States similar lights largely used are the Gregory incandescent and the Gleason "Beacon" lights.

I will next consider the *high-power* or *regenerative gas burners*. In all burners of this type the high temperature due to the combustion in the gas flame is directly utilized to raise the temperature of the gas before ignition, or of the air supply before combustion, or of both, the result being an intensified and more perfect combustion, and a vastly increased illuminating power. All regenerative lamps produce a higher efficiency of candle-power per cubic foot of gas consumed than is secured by ordinary burners, the burners are economical in gas consumption, and the light produced is intense and steady.

One of the first regenerative burners was the Siemens burner, invented by Friedr. Siemens in 1879. In its original form this burner is a round-flame burner in which the flame burns around a central porcelain cylinder, over the top edge of which it turns. From this point the products of combustion pass downward through a central flue, and in their passage they heat a chamber through which the air passes upward, becoming highly heated by contact with the burner body. The products of combustion are then carried to the escape pipe by means of one or two side tubes.

This first regenerative burner gave a very powerful light, but it was clumsy and inelegant in form and appearance, the shadow cast by the large body of the burner was objectionable, and hence, it did not find much favor for interior lighting, although it was extensively applied for the lighting of streets, squares and parks and large halls. Regenerative gas lamps have since then been modified and constantly improved, and the Siemens inverted regenerative lamp is now manufactured in several different forms.

The Lungren regenerative lamp, which resembles the Siemens, is practically an inverted Siemens lamp, in which the flame burns outward and upward around a central shell which it heats to a high temperature. The air supply enters above the flame by means of tubes extending across the escape flue, and passes down on both sides of the flame. The flame is enclosed in a clear glass bell, semi-globular in shape, which is supported by a hinged ring.

Other regenerative lamps, some having the flame burning from the inside out and others from the outside towards the inside, and all similar in principle, but different in details of design and construction, are the improved Siemens, the Wenham, Bower, Clark, Grimston, Thorp, Gordon, Sugg, Bray, Brown's "Brilliant," Fullford, Meteor, Butzke, Westphahl and Muchall lamps.

For dwelling-house illumination regenerative lamps have, up to the present time, been used only to a very limited extent, although the fact that nearly all of these lamps are powerful ventilating agents and may be made to assist materially in the removal of the vitiated air of apartments, would

seem to recommend them particularly from a sanitary point of view. Their application has been largely confined to special cases, such as the lighting of large halls, stores, and for lighting streets and squares, and wherever used they have proven to be very economical in gas consumption. The burners of regenerative lamps are somewhat complicated, require nice adjustment and are liable to clog up with deposits of carbon, and need, together with the enclosing glass globe, frequent cleaning and attention. This, together with the high price of the lamps, has also acted as a drawback against their general introduction.

Among the latest regenerative gas lamps, especially adapted for interior lighting, I mention Sugg's patent "Cromartie" gas lamp. In these lamps "a special form of steatite burner is used inverted, with the object of retarding the motion of the carbon particles through the length of the flame, thus allowing sufficient time for the oxygen of the atmosphere to combine with the carbon of the gas in combustion. This arrangement produces an intensely white flame in the form of a camelia, diffusing a perfectly steady white shadowless light of great illuminating power." Each lamp is provided with a Sugg automatic leather diaphragm governor. These Cromartie lamps are made in two forms, either as ventilating or as non-ventilating lamps. In the ventilating lamps the heat developed by the combustion of gas is not only carried away without entering the room, but it is utilized to assist in educing heat or vitiated air from the apartments. In the case of smoking rooms this arrangement is particularly effective, and all smoke is rapidly conducted to the exterior. The air at the ceiling level is kept cool and pure, and furniture, pictures and gilt frames are not subjected to damage. The Cromartie lamps are said by experts to produce very high results in candle-power, the quality of the light is said to be excellent, and as these lamps are gotten up in a variety of pleasing and artistic designs, shapes and colors, they lend themselves admirably to decorative lighting.

Mr. MacFie, gas engineer, of the firm of Milne, Sons & MacFie, in a paper read at the annual meeting of the North

British Association of Gas Manufacturers in Edinburgh, in 1891, has pointed out one notable feature of all regenerative lamps, namely, that they throw the light downwards where wanted, whereas all flat-flame burners tend to light up the ceilings and upper parts of wall.

A further advance in the perfection of gas lighting has been made by the invention of *incandescent gas burners.* In these burners the heat of the flame is utilized in the raising to incandescence of some refractory substance introduced into the burner which is usually an atmospheric or Bunsen burner. This substance may be a basket of platinum, as in the Lewis burner, or a conical-shaped basket of a net work of magnesia as in the Clamond lamp, or a row of finely shaped parallel suspended rods of magnesia such as is used in the Fahnejelm light, or finally a funnel-shaped wick or mantle of cotton treated chemically with sulphate of zirconium, and other rare elements, such as yttrium, didynium and lanthanium, as seen in the Welsbach incandescent burner.

The Clamond and the Welsbach incandescent gas lights are being used to a great extent in Europe, and the Welsbach light to some extent in this country. The former is the invention of a Paris chemist, the latter of a Vienna chemist, Dr. Auer von Welsbach.

After being first put on the market the Welsbach burner disappeared again, owing to various imperfections. It has now again reappeared, in an improved form, as claimed by its manufacturers, but however beautiful the Welsbach incandescent light when the mantle is new, its light rapidly deteriorates and loses in intensity, and this is particularly the case where the atmosphere carries much dust, which settles on the mantle forming a sort of incrustation, which renders the light less incandescent and changes it from white to red. The chief objection to the Welsbach light which renders it undesirable for ordinary domestic use is, that the cotton mantle is extremely delicate and readily breaks, also that the glass cylinders surrounding the filament crack at times and in doing so break the mantle. As the mantle is expensive, the Welsbach light,

although undoubtedly very economical in the use of gas, proves in the end quite costly. Among its other advantages are the steadiness of its light, particularly when used with a volumetric governor, and the decreased radiation of heat as compared with other high-power gas lamps.

Quite recently the Welsbach incandescent lamps have been used in some European cities for street illumination, and it is claimed that favorable results have been obtained as regards lighting power.

My description of gas burners would be incomplete without a mention of the *albo-carbon light*, which gives a much increased illuminaticn and a very white, soft and steady light, by the carburetting of the ordinary gas. This process consists in supplying to the ordinary gas, at the gas burner, a further amount of carbon illuminants. The enriching solid carbon material is kept in a vessel combined with the gas fixture, and the heat of combustion of the gas flame is used to preheat the gas supply and to vaporize the carbon, which thus enriches the gas, and effects a saving in the gas consumption.

[*To be concluded*]

THE ELECTRIC MOTOR.*

BY PROF. F. B CROCKER, of Columbia College, New York City.

The lecturer was introduced by Prof. E. J. Houston, and spoke as follows:

MEMBERS OF THE INSTITUTE, LADIES AND GENTLEMEN:

A single lecture cannot possibly do justice to a subject of the magnitude and importance of the electric motor. There are, however, certain salient and interesting points which, when touched, give the keynotes of the entire subject. Some of these are contained in the history of the electric motor, and others in the action of the machine itself.

* A lecture delivered before the Franklin Institute, Philadelphia, January 19, 1894.

In taking up the historical consideration, we have the amber of the ancients as the first electric generator, corresponding to the dynamo, and its attraction of feathers and other light bodies as the first artificial production of motion by electricity, corresponding to the electric motor. I say *artificial*, because lightning has from the beginning of the world caused powerful movements and disturbances in the bodies which it strikes. Thus the birth of these two important machines was simultaneous; indeed electricity was discovered solely by the fact that it produced *motion* under conditions which were peculiar, and it seemed to be so different from all other natural phenomena that from those early times, even up to the present day, it is looked upon as the most wonderful and mysterious agency in nature.

The magnetic attraction of pieces of iron by the lodestone was also observed by the ancients, and the electric motor of the present day is more directly based upon this phenomenon than upon the electrostatic attraction caused by amber.

From those early times up to the present century, particularly during the last century, numerous experiments were made with magnetic and electrostatic attraction, but no one produced any results which can be considered to be any more like an electric motor than the simple experiments of the ancients. The first apparatus which in principle and construction sufficiently resembled the machines of to-day, to be properly regarded as an electric motor, was Barlow's wheel, described by him in his work on "Magnetic Attraction," published in London in 1823. This invention is remarkable in the fact that it antedated by eight years the disc machine of Faraday (which was the prototype of the dynamo), and his discovery of magneto-electric induction in 1831. Not only was Barlow's wheel far ahead of Faraday's disc in point of time, but it was also a much better construction, because the former was made in the shape of a star with long points so that the current was confined to the particular portion of the wheel which was between the poles of the magnet. In Faraday's disc, on the

other hand, the current produced in that part of the disc actually between the poles was at liberty to flow back through all the rest of the wheel. The armature was, therefore, completely short-circuited in itself, a feature which we know to be one of the worst faults that it can possibly have, and the amount of current obtained in the external circuit was an almost infinitesimal fraction of that produced, being only sufficient to deflect a galvanometer needle. It was, indeed, a fortunate thing for science that any perceptible effect whatever was obtained, otherwise the most important discovery of the nineteenth century might have been delayed.

Joseph Henry, in 1831, was the first to construct a motor which worked by electro-magnetic attraction. This apparatus really has a better right to the distinction of being called the first electric motor than Barlow's wheel. Many other inventors followed Henry in devising forms of electro-magnetic motors. Jacobi in 1834, Davenport in 1837, and Page in 1838, are particularly worthy of mention. Some of these early motors were by no means mere toys, but were of considerable size and power. Jacobi, of St. Petersburg, in 1838, propelled a boat twenty-eight feet long at a speed of three miles an hour; and Page, of Washington, in 1851, succeeded in obtaining a speed of nineteen miles per hour with a car carrying a number of persons and driven by a sixteen horse-power electric motor. This result, by the way, is practically the same as that obtained from the most improved trolley cars of to-day, both in speed and power.

This brief glance at the early history of the electric motor brings out the striking fact that this machine was invented eight years before the dynamo and for several decades it was considered of more importance, both scientifically and practically; the motors of Jacobi and Page, for example, being far more powerful than any contemporaneous dynamo. A search through the patent records of the United States and England would show also that more attention and greater expectations were then based upon the motor. This was undoubtedly due to the fact that inventors hoped to obtain a source of power which would rival or

surpass the steam engine. It was gradually realized, however, that the cost of electrical energy obtained from a primary battery is so high that it cannot compete with a steam engine. The number of pounds of zinc consumed in the best battery, per horse-power hour, is about equal to the weight of coal required to give the same amount of energy in a steam engine; and since zinc costs about fifty times as much per pound as coal (in fact it actually requires several pounds of coal to produce one pound of zinc), it is obvious that the primary battery is far more costly than steam in the generation of power. As a matter of fact, electrical energy from a primary battery at the present time costs at least ten times and probably twenty times as much as that obtained by the use of a steam engine and dynamo.

The realization of this serious difficulty greatly discouraged scientific men and inventors in regard to the electric motor. A reaction set in against it, and for many years it was comparatively neglected by the best workers. The dynamo was taken up in its stead and developed in the remarkably rapid and successful manner which is the greatest practical achievement of recent times. The neglect of the electric motor continued until about 1887, the dynamo having by that time reached a state of great perfection and being in extensive use for electric lighting. The development of the dynamo, and the laying of electric light circuits through the streets of many cities and towns, provided the very supply of reasonably cheap current which was needed for the motor, and which the primary battery had failed to give.

This fact encouraged inventors and manufacturers to again take up the motor, and since that time its progress in this country has been very rapid; but even now the motor is somewhat overshadowed by the dynamo. The number of electric motors in use in foreign countries is not very considerable, but in the United States there are probably about 50,000 stationary motors and several thousand railway motors, whereas the number in the whole of Europe is not much more than one-tenth of these figures. This last fact probably explains why the literature of the dynamo is

much more complete than that of the motor, since most of the books are written by Europeans—the time of Americans being occupied rather with *making* and *using* dynamos and motors than with telling others how to do these things. The most recent history of the motor includes the invention, by Tesla, in 1888, of the two-phase alternating current motor and the development of the two- and three-phase systems. These important systems are now being practically used, and an enormous electric power transmission plant is being installed at Niagara Falls, which is to be operated by the two-phase system. Indeed, it may be said that the progress of the electric motor at the present time is equally as rapid as, and more interesting than, that of the dynamo.

If the dream of the electrical engineer should be realized and electrical energy could be obtained directly from coal without the use of the steam engine and dynamo, then the importance of the electric motor would be paramount, and it would be used in practically every case where power is needed, while the steam engine and dynamo would be relegated to scientific museums where they would be gazed upon as mere historical curiosities. This time may come in a few years, or perhaps not for centuries, but no one will dare deny its possibility, and many of the greatest thinkers and experimentalists are now working in that direction.

The points in the history of the electric motor to which I desire to call particular attention are these: that for many years it was considered of greater importance than the dynamo; that it then fell into a position of comparative insignificance, but that in the last few years it has again become very prominent, and in the future it is certain to be of still greater importance, while the dynamo may become obsolete.

In considering the construction and action of the electric motor, the first and most important fact is its great similarity to the dynamo, or, more strictly speaking, it is practically the same machine used in exactly the opposite manner. The dynamo is a machine which generates electric current when driven by mechanical power. A motor is a machine that develops mechanical power when supplied with electric

current; thus the functions of the two machines are exactly the converse of each other; nevertheless, identically the same machine can be used for either purpose, that is to say, the machine is perfectly *reversible*. It is also a fact that a machine that is good for one purpose is good for the other. The old idea that a good dynamo was not necessarily a good motor, and that considerable differences in construction are required, is, so far as the writer's experience goes, a fallacious one. The tendency now is for manufacturers to make exactly the same machine and use it for either purpose indiscriminately with only very slight differences in the details of winding, connections, etc.

While it is true that the two machines are practically identical in construction, nevertheless, their actions are somewhat different, and this difference is just sufficient to be puzzling. It seems to be a fact that knowledge concerning the motor is much less general and much less perfect than knowledge of the dynamo. The reason for this is probably that most persons fail to understand these slight differences in action and are therefore apt to assume either that the two machines are exactly alike or entirely different, neither of which assumptions is correct.

The key to the action of the motor and particularly to the difference between it and the dynamo is its *counter electromotive force*. In the case of the dynamo there exists only one EMF, whereas in the motor there must always be two. The difference between the two cases may be expressed very simply in the following way:

One Kilowatt dynamo,

$$C = \frac{E}{R} \qquad (1)$$

$$10 \text{ ampères} = \frac{100 \text{ volts}}{10 \text{ ohms}}$$

One Kilowatt motor,

$$C = \frac{E - e}{R^1} \qquad (2)$$

$$10 \text{ ampères} = \frac{100 \text{ volts} - 90 \text{ volts}}{1 \text{ ohm}}$$

C is the current;
E, the direct EMF;
e, the counter EMF;
R, the total resistance of the circuit;
R^1 the resistance of the armature.

The current and direct EMF are the same in the two cases, but the resistance is only one-tenth as much in the case of the motor, the difference being replaced by the counter EMF of 90 volts, which acts like resistance to reduce the current.

The counter EMF of a motor is the *necessary* result of the rotation of its armature, as I will now show you by the following experiment. We have here two identical machines, one of them being connected to the electric light circuit, the current from which causes the machine to run as a motor. This machine is belted to the other machine, which is thereby driven as a dynamo. Now in both cases we have identical armatures revolving at equal speed in magnetic fields of practically the same strength. It is obvious, therefore, that nearly the same EMF must be generated in each machine, because in both cases practically the same number of lines of force are cut by an equal number of turns of wire revolving at the same speed. In the case of the dynamo this EMF produces a current which may be used to feed a certain number of incandescent lamps. In the case of the motor the EMF is opposed or counter to the direct EMF of the electric light circuit, and the current produced is due to the difference between the two, as expressed in equation (2).

It may be asked why this EMF is necessarily a counter one. The answer is that if we trace out the direction of the motion and of the lines of force, we shall find in every case that the EMF generated is opposed to that which produces the rotation of the armature. This in fact necessarily follows from Lenz's law. The real significance of the counter EMF is that it represents the amount of electrical energy that is taken out of the electrical circuit, so to speak, and converted into mechanical energy.

This is the way in which nature always works in converting electrical energy into any other form of energy, with the single exception of the production of heat by the passage of

current through a resistance. This last, however, is not a true case of conversion, being a frittering away of energy similar to the production of heat by friction. In all other cases the counter EMF is always present. For example, when electrical energy is converted into chemical energy in the charging of a storage battery, or the decomposition of water, there is in every case a counter EMF. In the same way, when an electro-magnet is charged and electrical energy is converted into magnetic energy there is a counter EMF which opposes the magnetizing current and is commonly known as the counter EMF of self-induction. Even when electrical energy is converted into heat by the Peltier effect there always exists a counter EMF which represents the conversion of energy, this being a reversible process, and, therefore, a true case of conversion, which, as already stated, is not the case when heat is produced by mere resistance. This counter EMF is indeed a most remarkable and interesting phenomenon and throws considerable light upon the relation of the various forms of energy and the manner in which one is converted into another.

In the case of the motor, the counter EMF actually represents the amount of electrical energy converted into mechanical energy, and therefore determines the efficiency the so-called electrical efficiency, or conversion-factor, being equal to

$$\frac{\text{Counter EMF}}{\text{Direct EMF}}.$$

The actual or commercial efficiency is somewhat less than this, owing to friction, Foucault currents and hysteresis. The counter EMF also determines the speed and many other facts in the working of the machine.

In the minds of many persons the counter EMF is thought to be merely a "scientific idea" or a mathematical abstraction which has no real existence or importance. Nothing could be more erroneous than any such opinion. The counter EMF is just as real as the direct EMF. We have already seen that it must necessarily be produced whenever the armature revolves. It is somewhat difficult, how-

ever, to actually measure or show it. From its very nature it is covered up, so to speak, by the direct EMF. The ordinary way to determine it is to find the value of the direct EMF, the resistance, and the resulting current; the counter EMF is then found by the following equation, which is derived from equation (2): $e = E - CR$. It is also possible to calculate it in the same way that the EMF of a dynamo is determined, if the number of turns of wire, speed of rotation and number of lines of force are known.

The following experiment actually shows the existence and value of the counter EMF. We have here a plain shunt-wound motor provided with a fly-wheel, and we run it from a constant potential circuit of (say) 110 volts, and while it is running at full speed it is entirely disconnected from the circuit, but it will continue to run by the energy of the fly-wheel, and it will then act as a dynamo and generate an EMF of nearly 105 volts, which is tested by connecting a volt meter to the two brushes. This EMF is practically identical with the counter EMF which the machine was producing the moment before while running as a motor, provided, of course, the test is made immediately, so that the speed does not have time to fall appreciably. It should be remarked, also, that the strength of the field magnetism is slightly less, owing to the fact that it is fed by the EMF of 105 volts generated by the machine itself, instead of by the 110 volts of the circuit; but if the magnetism is nearly saturated this will only reduce the number of lines of force one or two per cent. Several incandescent lamps can be connected in parallel across the terminals of the machine and the energy in the revolving fly-wheel is sufficient to keep them glowing for one or more minutes. If a lamp is kept connected across the terminals of the motor while the switch controlling the circuit is alternately opened and closed, it is possible in this way to compare the direct and counter EMF by the variation in the brightness of the lamp, and it will be seen that the latter is only slightly less than the former.

A still more striking demonstration of the reality of the counter EMF will now be given by running the motor with a certain amount of resistance in its shunt field circuit, so

that the field magnetism will be below its normal value, in which case the speed will be higher than usual. If the machine is now disconnected from the circuit and the resistance is afterwards cut out of its field circuit, the EMF produced will become actually higher than the original direct EMF; in fact, it is possible to obtain two or three times the original voltage. We have here a new method of converting electrical energy to a higher potential, being a sort of direct current transformer, which, however, is quite different in principle from the ordinary dynamotor.

The important matter of governing the speed or power of electric motors depends largely upon the phenomenon of counter EMF. For example, the various methods of regulating street car motors, *i. e.*, the simple rheostat, the "loop" for short-circuiting one of the field coils, the "commutated fields" and the "series parallel controller," all act to adjust, or make up for, the variations in counter EMF which result from changes in speed. The most awkward matter in working electric motors is to control the current when the counter EMF is very low, due to the fact that the motor is starting or running slowly, and up to the present time there is no very satisfactory solution of this problem. The introduction of resistance in series with the armature is usually the simplest and most successful plan, but this is very wasteful of energy and involves the use of a large and clumsy rheostat.

The paradoxical fact that the speed of the ordinary shunt-wound motor increases if its field magnetism be weakened is also due to the counter EMF. This is easily understood if we remember that the counter EMF is reduced by weakening the field magnetism, consequently the current is increased in strength, as is evident from equation (2), and the speed therefore rises until the counter EMF reaches a sufficient value to shut off the excess of current.

The writer showed, several years ago, in his lectures at Columbia College, that a motor can easily be designed to run at the same, or at a *higher*, speed, when fully loaded than when lightly loaded. This may be done by slightly exaggerating the effect of armature reaction so that the field magnetism will be considerably reduced by the large

armature current which flows at full load, thus diminishing the counter EMF and increasing the speed in the manner just explained. In this way the remarkable effect of greater speed with heavier load is obtained without any special device or construction, all that is necessary being a slight modification in design involving no increase in cost or complication.

These examples demonstrate the great significance and importance of the phenomenon of counter EMF in the action of the electric motor.

EMERY AND OTHER ABRASIVES.*

By T. Dunkin Paret,
President of the Tanite Company.

The lecturer was introduced by the Secretary of the Institute, and spoke as follows:

Mr. Chairman, Ladies and Gentlemen, Members of the Institute:

In opening the consideration of the subject of my lecture, the first question that naturally arises is, what is emery?

I asked this question myself many years ago, before I ever had a thought of any connection with the industry of abrasive materials. On rainy days, in my early boyhood, my mother's sewing table, mahogany and claw-footed, was a source of unfailing interest. From its triple drawers and manifold little compartments, various wonders were evoked and from these wonders a small boy's curiosity evoked wonderful explanations. Among these wonders was a lifelike strawberry of red cloth, embroidered in green and yellow. Its brightness attracted me; its heaviness surprised me, and I wondered why my mother thrust her needle through the little strawberry. I asked her what the strawberry con-

* A lecture delivered before the Institute, February 9, 1894.

tained, and she answered, "Emery." I asked her what emery was, and she answered, "Steel dust."

Since then others have repeated the same question, and have received an answer fully as remarkable as the one my boyish ignorance drew forth. One of these answers, published several years ago in a mechanical paper, contains such a delightful mixture of fact and fiction, and is so characteristically expressed, that a few *verbatim* quotations may be interesting enough to place on record.

"Emery," says this oracle of the correspondents, "is a natural mineral rock, not found in mines or in strata, but scattered over more or less all the earth. It is a silicate of alumina, contaminated or mixed with a trace of iron. It is the matrix, or mother rock, of the ruby, the emerald and the sapphire. On account of the fact that emery is more generally found in Turkey or Turkish Asia, where labor is cheap, we procure emery from that country. Nearly 100 years ago, Robert Bruce Goldsworth, of Manchester, England, bought from the Turkish government a firman, or right, to collect and deal in emery. He formed the Levant Mineral Company, of London, and to this day emery is collected and mined by this body. Arabs (generally two, with a miserable camel) wander over the country with a bunch of jointed iron rods furnished with a steel point, so tempered and sharpened that, when they have reason to believe a lump or fragment of emery is below the soil which indicated it, they can, by jabbing at it with their steel rod, determine not only how deep it is buried, but also how large it is. If the indications are that it is of too great size for them to handle, they leave it. If the contrary, they dig it out—or pry it out—and by means of fire heat it; and when hot, crack it up by throwing water on it. When it is cracked and broken, so that they can handle it, they load it on their camel and carry it to Smyrna, where the foreman of the Levant Mineral Company buys it of them. In this crude way about all the emery of commerce is collected. The crude emery is sorted and corded up in grades, and vessels trading to that country for figs and other fruit load up more or less of it as ballast under their cargo." "This

is emery and its history. It is not found in mines, like coal, or iron, or copper, but as I have described, and, though it is claimed to be found elsewhere, Turkish Asia may be said to be its home, and the cheap, shiftless Arab laborers, who will work for days for a few piasters, is the reason, chiefly, that it is not looked for elsewhere. Almost every stone fence in the United States contains rock or boulders, which, if crushed and graded, would do the same work, but in this country it would not pay to collect it."

A much more important inquirer than this newspaper correspondent has lately asked the same question, "What is emery?" Unless we are mistaken, one of the questions addressed by the United States Government to those in the emery industry was whether they considered emery a chemical compound or a mechanical mixture.

Our own answer to the general question is, that emery is a mineral, of such rare occurrence and such mysterious origin, as to excite the interest of geologist and mineralogist. At some time in the past and by some means, both at present unknown, its special value as a grinding material was discovered, and it became an object of steadily growing importance in the industrial world.

We know of no facts bearing on the use of emery by the ancients. Archæologists have tried to prove that the ancients cut out their huge blocks of hard stone by the use of saws studded with corundum, but the evidence is of a negative character and purely fallacious. It seems to rest on the assumption that, as the diamond cannot be used for rock work, corundum must have been so used. It is a general belief, shared equally by workers and by scientific men, that carbon, or black diamond, is the only form of diamond which can be used to work stone, and there is no evidence that carbon, or black diamond, was known to the ancients. As a general rule carbon possesses a toughness which renders it a specially fit tool wherewith to drill rock or turn down solid emery wheels; while the gem diamond is so brittle that it breaks off quickly under the same work; and bort, so crystallized as to shiver easily into small pieces. But this general rule has so many proved exceptions, that

it is unsafe to connect definite qualities with the three species of minerals.

Until about fifteen years ago my personal experience confirmed the general belief. The diamond gem always proved too brittle for use, its points being broken off almost as soon as it touched a revolving emery wheel. Bort, of all varieties, proved far worse, and shivered to pieces. Carbon, or black diamond, seemed to be the only mineral hard enough and tough enough to cut down a revolving solid emery wheel, without being itself either broken or rapidly worn. Nevertheless, the very great variability in the quality of carbon ought to have suggested at an earlier date an equal variability in diamond and bort. The variation in quality of carbon is very great, some stones having very great lasting power, while others wear off so rapidly as to be absolutely useless. Carbon though they are, any common stone would do as well. As to their real value there seems to be no index. In the trade, unbroken crystals are considered more valuable than fractured stones, and the glossy black is preferred to gray. To such an extent does this question of color affect the choice that it is a common custom to blacken the carbon by artificial means. So misleading, however, are all the appearances, that, after many years' experience in the use of carbon, and in its observation under a powerful glass, the most experienced expert will sometimes select worthless stones.

My first experience of the unreliability of the general rule as to bort occurred to me probably ten or fifteen years ago, when two or three pieces were sent to me from Canada, with the statement that a friend at the Cape of Good Hope had sent them on as samples of a bort adapted to take the place of carbon. Thorough trial proved the correctness of this statement, but before any arrangement could be made the original sender had gone to India, and was lost sight of, and inquiry failed to discover the identity of the mine.

After the lapse of many years, in 1893, bort again came into notice for use instead of carbon, being offered at $2.50 per carat as against $16.50 for carbon. This bort has now had over six months' trial, and answers as well as carbon

for all except the very hardest use, though its shape is not quite so satisfactory. Thus far I have been unable to find out where this bort came from, or how its quality is ascertained.

In 1883, I bought 125 carats of diamond for $2 per carat. This was one-half of a lot left for sale with a New York firm, and its origin and quality were both unknown. This lot of 125 carats produced 260 tools, each containing an unbroken crystal, and all of these were as useful for turning solid emery wheels as was the more costly carbon, except as in the case of the bort, for the very hardest use; such use being the treatment of very hard wheels of coarse grain. These diamonds were much more satisfactory in shape than the bort. The remainder of the lot was removed from the city unsold and could not be traced.

As both diamond and bort could have accomplished the necessary work in ancient quarries, the claim that the ancients must necessarily have used corundum falls to the ground.

In no museum or cabinet have I ever seen an ancient tool of emery or corundum. The only emery tool of unknown age which has come to my notice is an Indian hammer stone of the ordinary type; but it is of emery and was found in 1893, in Westchester County, New York. As emery is a surface rock in some localities in that county, there is nothing to indicate that the quality of the stone dictated its choice, and its exceptional character would indicate that the Indians or other early inhabitants had not discovered the superiority of emery in hardness over the other surface rocks.

The natives of Ceylon and India use corundum with which to grind and polish gems. It is probable that this use has come down to them from their ancestors, but we have little knowledge as to the origin of the process.

Emery is essentially a modern commercial product, its use being dependent, firstly, on the enormously increased use of iron in very recent times; secondly, on those metallurgical processes which have produced steels, phosphor-bronzes, chilled iron and other specially tempered

metals; and thirdly, on that development of steam-power which has led to the use of high-speed rotary grinding tools.

Among the earlier uses of emery is its application to the lapidary's wheel. Its use on paper and cloth is also probably an early one. To this, succeeded the wooden wheel, banded with leather, which was coated with glue and rolled in emery. This was followed by the solid emery wheel. A still later production is the emery millstone. Glass, granite and the metals are the principal substances on which emery is used. The purposes for which it is used are roughly and rapidly to remove material—to shape and form, and to smooth or polish.

Emery was chosen for this purpose (before any commercial supplies of corundum existed), because of a grinding quality it was supposed to possess in a higher degree than that belonging to any other material. This grinding capacity was based on its rank in the scale of hardness among other minerals. The assumption that hardness was the main factor in its value has vitiated all judgments respecting grinding materials. Roughly speaking, emery was described as next in hardness to the diamond, and the superficial experimenter in testing a sample at once proceeded to notice how readily it would scratch glass or would crush under pressure. The next unfounded inference was drawn by those not altogether superficial observers, who sought to establish the value of a sample by a theoretical test. As alumina seemed to be the characteristic component of emery, that emery was deemed the best which contained the most alumina.

When corundum was found in such quantities as to be of commercial value, this theoretical text was urged strongly. It was pointed out that corundum contained a larger proportion of alumina than emery; that it contained none of that iron which was said to contaminate emery, and that it was, therefore, purer. Purity had been repeatedly claimed for corundum from different mines as a measure of value. In the sapphire corundum is said to take its most nearly perfect form, and in Klaproth's analysis of a blue sapphire,

quoted by Prof. J. P. Lesley,* the percentage of alumina is given as 98·5, and that of the impurities as only 1·5, the latter consisting of 0·5 per cent. silica and 1·0 per cent. iron. The peculiarity of the sapphire is that it is so fine and hard as to wear down, when ground, into smooth, flat faces. Such a stone, after being cut or ground, would scratch or cut only with its artificial angles, and these if much used would wear down to flat faces. If, instead of being held against a grinding wheel and so flattened, these gems were moulded into a solid wheel, they would, in like manner, flatten and would cease to cut as soon as their angles were worn away. Their fineness, their hardness and their purity, would be the very qualities which would unfit them for use as grinding materials.

Excessive hardness, therefore, is not the only requisite in a material used for cutting other substances. The most nearly perfect carbon will, if used for turning emery wheels, lose every point and corner and become a rounded mass, useless for further turning unless it is broken so as to present new angles.

Nevertheless, the supposed purity of corundum has invested it with such a fictitious value that the manufactured article has commanded as high a price as $200 per ton, when emery was selling for from $40 to $75. In museums and cabinets, specimens of corundum may be found which show distinct seams of bright, blue, transparent sapphire, and others of so-called ruby corundum, not transparent, but only suffused with a mild pink. If commercial corundum consisted of this blue transparent gem, purity would be the first thing claimed, the mere resemblance to sapphire and ruby being taken as a proof of purity.

Unfortunately for this assumption, Professor Lesley states that "both sapphire and ruby may be very impure corundum;" and he gives an analysis of a ruby containing only forty per cent. alumina and of sapphire containing only fifty-eight per cent.

Very little commercial corundum comes from sapphire-

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* *Second Geolog. Surv. of Pa.*, C 4, p. 352.

streaked seams, and scarcely any from massive rock: a small portion is produced from separate large crystals, which occur in some formations, scattered through a softer rock. The greater part, however, is found in large, decomposed and broken-down seams. In the case of the large crystals purity would depend on the care with which all traces of the matrix were removed. In the case of corundum sand, washed out of broken-down seams and beds, purity would depend on the separation of the corundum granules from the mixed mass of which they form a part.

The maximum purity of which we can find record is exhibited by the sapphire referred to by Professor Lesley as containing 98·5 per cent. of alumina. In reference to our assertion that, if crystallized in the form of a gem, corundum would be too fine and too hard to serve as a grinding material, it will be safe to qualify it by the statement that there might be some lower point at which purity had a real value. The practical question, therefore, is: how does corundum lately produced on a commercial scale compare with emery so produced?

In 1893, Dr. T. M. Chatard analyzed three samples of American corundum, purchased of three different mills. In these the average of alumina was 64·65 per cent. At the same time he analyzed three samples of emery from three different sources. The average of these was 60·94 per cent. of alumina, a difference of only 3·71 per cent. in favor of corundum. Of the three emery samples one was of that American ore which the combination of American emery mills has declared to be spurious and worthless. This American emery contained only 53·59 per cent. alumina, and if this sample were omitted the analysis would stand as follows: Corundum, 64·65 per cent. of alumina; emery, 64·62 per cent., a difference of three-one-hundredths of one per cent. in favor of corundum.

Of the three corundum samples, one contained only 37·31 per cent. of alumina, which is 16·28 per cent. less than the American emery contained. This corundum was of such color and general appearance that it might easily deceive the ordinary commercial user, and we are forced to believe

either that it did deceive its producers and sellers, or that they knowingly deceived the public. On going further into these analyses, we find that the American emery contained only 0·26 per cent. of silica, while the corundum just referred to contained 44·64 per cent. Going still further, we find that the corundum contained only 14·60 per cent. of ferric oxide, while the American emery contained 41·31 per cent.

In these facts we find a simple explanation of the popular delusion as to the superiority of corundum over emery. It is a question of color. The sapphire ranks next in hardness to the diamond, and is assumed to be a typically perfect grinding material. Corundum is a form of sapphire, occasionally containing traces of transparent blue sapphire, but characterized as a general thing by a yellow-toned whiteness. The 44·64 per cent. of silica in the so-called corundum furnishes that light color which characterizes corundum, while the 41·31 per cent. of ferric oxide in the American emery so darkens it as to disguise its higher proportion of alumina It does not require a chemical analysis to find this alumina in the emery. It is not obscured or hidden away in subtle chemical combinations. It is present often and freely as pure, blue, transparent sapphire, visible sometimes to the naked eye and easily discovered by a pocket magnifying glass. It can be seen at times, bright and blue, in the mass of a solid emery wheel, the general color of which is black, and if some of the dirty brown emery is sprinkled on a sheet of white paper and examined with a good glass in a good light, many grains will be found which are composed entirely of transparent, blue sapphire. If the unsightly ore is fractured at the ore heap it will often be found studded with the shining gem. It is not claimed that all emery is thus characterized, but the occurrence is so frequent as to prove that alumina in one of its highest forms of crystallization is a striking feature of old world emery.

If the commercial values of corundum and emery are based on their relative purity (a high percentage of alumina being considered the criterion), then these analyses show only a trifling superiority in the corundum. It may be suggested that these late analyses of Dr. Chatard are based on

unusually poor samples of corundum and unusually good ones of emery. To show that this is not the case we cite* nine analyses of corundum quoted by Professor Lesley, the average of which is 83·15 per cent. of alumina. So far as we can judge, none of these refer to American corundum, and none to commercial corundum, all of them relating to actual gems or cabinet specimens. We cite, also, ten analyses of Dr. J. Lawrence Smith.† These relate to samples of emery from four localities in Turkey and Greece, and the average of the ten is 67·97 per cent. alumina, or 7·03 per cent. more alumina than is shown by Dr. Chatard's analyses.

As popular belief assumes hardness to be the prime requisite in a grinding material, the question now arises as to whether hardness is definitely proportioned to the percentage of alumina. The ten analyses of Dr. Smith just cited give a striking answer. They show that the gradation of effective hardness does not correspond with the gradation of alumina. Assuming the effective hardness of East Indian sapphire as 100, the highest standard reached by any of Dr. Smith's samples was 57. This sample contained only 63·50 per cent. of alumina, while that which contained 77·82 per cent. (the highest percentage of alumina shown) ranked only 47 in the scale of hardness, or 10 less than did that sample which contained 14·32 per cent. less alumina.

These analyses throw a strong light on the popular delusion as to the injurious effect of iron as a constituent of emery. It is not an uncommon thing for buyers to say that some particular commercial brand of emery contains so much iron that they cannot use it. As a rule, no defect in use is set forth, and the inference is probably made from weight, from color, or from the action of a magnet. In the ten samples of emery analyzed by Dr. Smith, the lowest percentage of iron was 8·62, and the hardness 47; while the highest percentage of iron was 33·25, and the hardness 57. In this case quadrupling the amount of iron increased the hardness 10 per cent. While the gradations of hardness do

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* *Geolog. Sur. Pa.*, Chester County, C. 4, pp. 352, 353.

† *Am. Jour. Sci. and Arts*, **2**, x, 366.

not vary uniformly with the percentage of iron, it is a striking fact that in this one case the highest percentage of iron is accompanied by the greatest hardness.

While Dr. Smith's analyses show that a high percentage of iron does not imply a diminished hardness, Dr. Chatard's analyses show that a low percentage of iron does not imply a large percentage of alumina. That sample of corundum which contained only 2·90 per cent. iron contained only 72·26 per cent. of alumina, while that which contained 9·70 per cent. of iron had 84·38 per cent. of alumina.

It is not only the superficial user who is particular as to the amount of iron in his emery, for, in 1892, an enquiry for emery was sent out from one of our United States arsenals, which stipulated that the emery must not contain over 15·00 per cent. iron, and that it would be tested by the magnet.* Of the ten samples analyzed by Dr. Smith only two had so small a percentage as 15, so that it is doubtful if any commercial emery is to be found of the standard demanded in this case by the United States Government. It has already been shown that the maximum hardness of these samples was 57, and that the sample which had 8·62 per cent. of iron ranked only 47. The only other sample low in iron contained 13·06 per cent., and ranked only 46.

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* Since the delivery of this lecture an order has been sent out from one of the United States arsenals for emery "averaging not over ten per cent. of iron, to be tested by the magnet." As I can find only one analysis which shows less than ten per cent. of iron, it is almost certain that no commercial supply exists, and that such a demand could only be met by the use of some very rare lot.

The wording of the demand implies that the percentage of iron is to be determined by the magnet.

As a recent letter from a corundum company appeals to the magnet test as a proof of the purity of its corundum, asserting that certain Southern corundum contains thirty per cent. of iron, I have had samples of three lots of corundum, from two producers, pulverized so as to go through a cloth with 200 meshes to the lineal inch. I find that this dust is so impregnated with iron that the magnet will attract and remove *every particle*, there being no residue at all.

If emery is to be condemned because the magnet attracts it, why is not corundum also condemned? Probably because of the unwarranted assumption that commercial corundum lives up to the letter of its type and is free of iron.

Analyses* of emery made by different authorities vary considerably in form. Most of them make no distinction as to the character of the alumina, but class it all under one head. Dr. Smith's analyses are of this nature, though he distinctly says that "we must not always regard the quantity of alumina as an indication of the quantity of corundum in the emery." Dr. Chatard's analyses follow a different plan. They make a distinction between dissolved alumina and insoluble corundum. Of the three samples of corundum analyzed by Dr. Chatard, one contained 47·60 per cent. of insoluble corundum, while one sample of emery almost equalled it and contained 40·21 per cent. A second sample of corundum contained only 36·49 per cent., and a third none at all. This last affords the astonishing contrast of a commercial corundum, possessing some of the external features of the genuine article, sold at the highest market price, and whose analysis shows no insoluble corundum at all, while a commercial article of American emery, whose enemies declare it to be spurious and worthless, contains 10·14 per cent. of insoluble corundum

While the reputation of corundum depends partly on its supposed possession of a high percentage of alumina, it is also based on that standard of effective hardness, whose origin is credited to Dr. Smith. His method (often adopted by later investigators) was to place emery or corundum on a piece of glass, rub the emery over the glass with a piece of agate, until the emery is reduced to an impalpable powder, and then to weigh the glass and ascertain the amount removed. Sapphire was treated the same way, and

* As bearing on the comparative hardness of corundum and emery, a tabulation of Dr. Smith's is noticeable.[1] He shows the average effective hardness of six samples of eastern corundum to be 62, the highest being 77 and the lowest 55. The average effective hardness of the first six samples of emery in same tabulation is 52, the highest being 57 and the lowest 46. The three poorest samples of corundum (out of six) foot up 170° of effective hardness, while the three best samples of emery (out of the six averaged above) foot up 169. If, therefore, effective hardness is the great desideratum in abrasives, it would seem that $150 a ton is a large bonus for corundum buyers to pay on such chances as this tabulation indicates.

[1] *Am. Jour. Sci. and Arts*, 2, xlii, 89.

its result stood as 100 in the scale. This method appears, at first sight, to be exact, but it assumes a uniform hardness for sapphire, though such uniformity is doubtful in the extreme, and it also assumes uniformity in the resisting power of glass, which uniformity is equally doubtful. Its greatest defect, however, is that it omits two of the most important factors in the economical or commercial problem, *i. e.*, the time and the power. Even if it does determine the effective hardness of grinding materials it does not determine their grinding capacity in any such way as to establish relative commercial values. The commercial question is not settled by the statement that a given material will grind off a given amount of glass or metal. It must also be stated how long it takes to grind and how much power is consumed. This question will be considered later.

Even if it could be proved that the relative hardness of corundum and its percentage of alumina entitled it to a higher commercial value than emery, the manner in which corundum occurs at the mines makes it doubtful if a uniform product can be secured. In one form, probably the purest, it occurs in thin seams of bright blue sapphire, coated with a mineral of totally different nature. In another it occurs as distinct crystals of considerable size, encased in a softer matrix. As an example of this latter, I here exhibit crystals recently obtained from Lehigh County, Pa. In another form it occurs in decomposed or broken-down seams. Dr. Chatard remarks* that "the crushing of emery is generally much easier than that of corundum, though in this respect great differences often exist between the corundum of different localities and even in that from different parts of the same mine. This is probably due to the tendency of corundum to alter or weather. The researches of Prof. F. A. Genth and others, have shown that it yields readily to the action of mineral solvents, becoming softer and more friable, the alumina uniting with other substances to form various other minerals." * * * "Even when the change is very slight and invisible to the

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* *Min. Resources of U.S.* U. S. Geol. Survey. 1883–84, p. 718.

eye we may have a material apparently solid and unaltered, which though crushing easily and giving a product of good appearance, not only yields too large a proportion of the comparatively useless 'flour,' but even a grain deficient in cutting effect."

No such crushing indictment as this can be brought against emery. It has no such tendency to weather and decompose. Sand veins are unknown and the emery rock occurs in mass. We have noted only two exceptions to its character for absolute stability. Professor Shepard has reported a gain in weight of manufactured emery amounting to two per cent., which gain was due to oxidation. An old sample case of "Wellington" emery, which had remained many years unmoved in a garret impressed me with the truth of Professor Shepard's report, but I have only met with this one instance. I cannot believe that as a common thing it undergoes any change whatever in composition. If acids or other artificial agents were employed to give that reddish-brown color which is mistakably accepted by some as a criterion of good emery, that might account for oxidation after manufacture. The other exception occurs in the case of some American emery. This emery is sometimes found in amorphous masses of considerable size, often of many tons weight, surrounded by earth and detached from other rock. Where these masses thin out at the edge they occasionally contain iron pyrites, and the rock thus tainted crumbles to pieces after short exposure to the weather. The indications of this taint are so clear that there is little excuse for one who mines such ore. As a rule this contamination affects only a small part of the edge of the mass; so small a part that it is not easy to see how even careless mining could have furnished enough to greatly lower the general average quality of the rock. I have seen one large deposit, however, where the presence of pyrites is so general as to suggest doubt about the average quality. A very old ore pile of many tons gives evidence of some change since the ore was mined, though there is no serious crumbling. It is quite possible that the mining of such ore gave American emery that bad character which effectually stopped its sale about twenty years ago.

Professor Shepard cites reports from the United States Arsenal, at Springfield, Mass., which make a most favorable showing for the emery mined in Hampden County, Mass., when such emery was used under so-called test conditions, and compared with corundum. On the other hand, it has been stated on good authority that this emery was so soft that it crushed down like mud and that the workmen would not use it. While it is possible that these contradictory verdicts or results may be reconciled by the existence of a real and great difference in quality, it is probable that the test was reasonably accurate and the bad opinion based on prejudice or misuse. Appearance probably had much to do with it. That emery which was considered standard had a reddish-brown color after manufacture and when offered for sale. This color was erroneously considered a necessary indication of good emery, while the emery from Hampden County, Mass., and Westchester County, N. Y. (which were put on the market about the same time), lacked the reddish-brown color, and presented a mixture of black and white. The white was at once condemned as an impurity and considered as an admixture of softer stone; and the same public which, of late, has set a high value on corundum, because of its whiteness, set a low value on American emery for the same reason. It is a fact that unbroken lumps of Greek and Turkish emery present, commonly, a reddish-brown appearance and that the emery of Westchester County, N. Y., when broken according to its natural seams and clearages, often shows the same color. The oxidation which causes this is the result of slow action during hundreds and thousands of years, and internally the color is different. A clean fracture of American ore shows color from glossy black to deep blue and light gray. The only colors mentioned by Dr. Smith for Greek and Turkish emery are dark gray, dark blue, and dark blue bordering on black. Dr. Smith says that "when reduced to powder it varies in color from dark gray to black. The color of its powder affords no indication of its commercial value." Nevertheless a reddish-brown color is the test of orthodoxy in emery, and the public regards all other colors with suspicion. Any

distinctive color imparts uniformity of apppearance, and, though emery is a mechanical mixture of most varied character, the public prefer uniformity in appearance.

The differences in composition of emery revealed by chemical analysis are confirmed by observations of a more general nature. Dr. Smith enumerates several varieties. One has "small points of a micaceous mineral disseminated in the mass." Another is fine grained and free from micaceous specks. Another is coarse grained. Another lamellated and containing an abundance of micaceous mineral. Dr. Smith also states that specimens containing the same amount of corundum differ in their effective hardness. These observations, reported in 1850, are confirmed by the later ones of Mr. W. E. Stevens, United States Consul at Smyrna in 1885.* Mr. Stevens speaks of the ore from three mines as being of nearly equal quality "when well picked and free from unsound ore and waste." He states that it is picked at the mines, in some instances, not one-half being selected, and again picked before shipment. At one place the emery is not much sought after. At another "a great deal of the emery is not mined, owing to the presence of mica in the grain." One ore "is of inferior quality, the grain being smooth and a great deal of magnetic iron entering into its composition." Some of the ore is in its natural state, while some has been subjected to fire, and there are frequent shipments of "inferior or uncleaned stone." Mr. Stevens also states that the abrading power "does not solely depend upon the alumina it contains, but also upon the particular way in which the particles have been placed by nature."

Certain general impressions as to the relative value of different varieties of emery have long influenced the public. A great superiority has been claimed for Naxos emery and a high price is asked for it, but even those skilled in the industry do not seem convinced of its superiority, or, if they admit it, do not consider it a reason for much higher price. Turkey emery is accepted by the general user without any

* *U. S. Consular Reports.* No. 55. August, 1885.

stipulation, except that it be Turkish, though emery mills attach special values to different mines. It appears, however, that no distinctive character really attaches either to Greek or Turkish emery, the quality ranging from first-class to worthless. Good ore is a matter of selection.

This being so, the question arises, what are the chances of getting a well-selected ore? These depend largely on questions of collection, distribution and transport. The unconscious humorist, whose "answer to correspondents" was quoted at the beginning of this lecture, gives one clue. The two Arabs, with a miserable camel, wandering over the back country, and taking or leaving according to size, indicate the crudeness of method and the smallness and great variety of the original finds. He gives another clue when he ascribes the supremacy of Turkey in the emery trade as due to "the cheap, shiftless Arab laborers, who will work for days for a few piasters." Recent progress has somewhat changed matters, for Mr. Stevens says that the Italian overseers and principal workmen get eighty-two cents a day, and the natives about half as much. He speaks of mines opened by wells and galleries, of the free use of gunpowder and dynamite, and of stone being mined at such depth as to require a steam pump. He speaks of the railroad as a means of transport. But it is evident that something of the crude method still survives, and that the railroad station is only a final touch of civilization to a somewhat heathenish course of production; for Mr. Stevens says that "when the mines are situated on heights inaccessible to camels, the ore is brought down to the plains by donkeys. If the pieces are too large to be carried by camels, they are brought to the station in carts drawn by buffaloes." The coast is the ultimate place of collection, and Smyrna seems always to have been the chief port of shipment. In fact, Dr. Smith states that even the emery from the Greek islands went to Smyrna.

It seems clear that emery of the most diverse qualities is gathered in small quantities from many localities, and collected in mass at the coast. From the coast, the places

of consumption are remote, the United States, Great Britain, Germany and France being the principal users. Just as the tutelary commercial deity of Italy has provided it with light weight and bulky rags as an offset to its heavy marble, and so rendered the shipment of both profitable; so had the tutelary commercial deity of Turkey provided emery ore as an offset to its licorice and dried fruits. The result is that emery is shipped, not in accordance with a natural demand in the countries of use, but, according to varying nautical needs, for ballast. After having drifted down from the Turkish mountain tops by donkey, camel and cart—after being lightered from Naxos, Nicaria and other islands to Syra, the masses thus collected begin again to drift away. They pass into the hands of agents, brokers, speculators, shippers and ship-loaders. In lots of 20, 40 and possibly sometimes 100 to 200 tons, they drift, in a sort of irresponsible way, to the docks of London, Liverpool, New York, Boston, etc., where they are handled by brokers, who usually sell by sample. Sometimes the buyer selects at the dock, and some mills make special contracts for special ore. Small lots are frequently offered by brokers, and job lots at low prices are also offered, notwithstanding a fixed general market value. As a rule, the seller has no data to offer concerning quality, and the buyer has to look out for himself. Sometimes he is told the Turkish name of the mine, or is informed that this ore is a new find of some Greek gentleman, independent of the Sultan's concessions and the Greek Government's monopoly, or else he is assured it is exactly the same ore as that which the Wellington Mills professes to monopolize. The real fact is that much emery is unbaptized, unsponsored, unfathered, and the chance of a continuous supply of uniform quality rare in the extreme.

Notwithstanding these variations the average quality of Greek and Turkish emery is such that it finds a steadily increasing sale in the United States, although this country has, for the last five years, furnished an important product.

Our average annual imports of emery ore were:*

	Pounds.
For the decade ending with 1878,	2,376,743
For the decade ending with 1888,	7,315,165
For the five years ending with 1893,	10,705,049

Our average annual imports of emery in grains, ground, pulverized and refined, were:

	Pounds.
For the decade ending with 1878,	621,807
For the decade ending with 1888,	589,054
For the five years ending with 1893,	569,019

The total average annual imports of ore and grain were:

	Tons.
For the decade ending with 1878,	1,338
For the decade ending with 1888,	3,521
For the five years ending with 1893,	5,637

These figures are necessarily incomplete as to 1893, but probably bring down the facts to November.

Side by side with this largely increased importation, is a largely increased native product; for corundum, the average annual output of which, from 1881 to 1888 (both inclusive), was 573 tons (2,000 pounds each), has been supplemented by emery, and the average annual product of the two for the four years ending with 1892, was 2,058 tons.† This gives a total of about 7,700 tons.

While this increased consumption demonstrates the growth of those industries which use emery and corundum, it does not measure the total use of abrasives. Some of the glass works which formerly used emery largely, have given it up and now use silica, while chilled shot and crushed steel have displaced emery to a certain extent among the granite workers. It is worthy of note that the United States Government has, for many years, maintained in its annual report on *Mineral Resources*, a separate department for "abrasive materials." In the Mines and Mining Building, at the Columbian Exposition, abrasives were grouped by themselves.

* United States Treasury Department.

† *Min. Resources of U. S.* 1892. U. S. Geol. Survey, p. 751.

The growing importance of abrasives is such as to suggest inquiry concerning our future supply. At present, we depend, for the larger part of this, on remote foreign lands. Practically on one land, for the emery-bearing Greek islands lie so close to the coast of Asia Minor that they are geographically Turkish and only politically Greek. The ore all passes through a few ports, and the ever unsettled Eastern question might at any time precipitate a war, and the blockade of these ports. The *Encyclopædia Britannica* mentions the occurrence of emery in Sweden, Spain, Saxony and Greenland, but Turkey and Greece are, apparently, the only foreign countries which afford a commercial supply. Thus far our supply of native emery has come from New York and Massachusetts, while the corundum has come from Pennsylvania, North Carolina and Georgia. Some hope of new sources is suggested by the humorist already quoted, who says that emery is "scattered over more or less all the earth," and also by the stream of letters which, for years past, has flowed in upon wheel and emery makers, offering corundum mines from Washington, on our northwest coast, to South Carolina, on the southeast.

[*To be concluded.*]

ENGINEERING PRACTICE AND EDUCATION.*

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If any one among my hearers expects me to begin this lecture by giving a definition of the words *Engineering* and *Engineer*, I am afraid he will be disappointed. Definitions are attempts to describe, or to give the distinguishing characteristics of the thing defined, in a very few words. To give them is comparatively easy when the things defined are of limited scope; but the more extended the scope, the

* A series of six lectures prepared for delivery in the Lowell Institute, in Boston, Mass.; the last three of which were not given on account of the sickness of the Author.

more difficult does it become to circumscribe them within the bounds of a definition.

Indeed, the term *Engineering* has been used with different significations at different times, and what has been its accepted meaning at any one time has depended upon the particular condition of the world's industrial progress at that period.

Without going into a great many details, I may say that the definition of the profession of the *Civil Engineer*, adopted by the Council of the British Institution of Civil Engineers, in 1828, was, "the art of directing the great sources of power in Nature for the use and convenience of man." Such a definition as this is not only vague, but, if taken literally, it would include a range of work far more extensive than that which has ever been or is now understood as the province of the engineer. Nevertheless, the converse is true of the engineer (omitting the limiting term civil), *i. e.*, the engineer must, in the practice of his profession, direct the great sources of power in Nature for the use and convenience of man.

At one time, when the science of engineering was still quite limited in its scope, there were only two designations used, viz.: military engineering and civil engineering, the latter term denoting all engineering which was not military.

Later on, as the science, and hence the scope of engineering, advanced, and as engineers began to devote themselves to special lines of work, there arose a large variety of designations, some of which are: civil engineering (no longer used in the original sense), mechanical engineering, mining engineering, etc., and it was assumed that these professions were quite distinct from each other. Indeed, this idea seemed to be in accord with the natural drift towards specialization, and in the line of progress. Now, however, that the tendency towards specialization is ever on the increase, and that progress has gone farther, I think that any one who will examine the facts carefully, and in a judicial frame of mind, will be satisfied that while all these different kinds of engineers are applying their art to a specialty, nevertheless, the art is one, and the functions

of the engineer comprise one definite, though wide and extensive, range of work.

We will now proceed to consider some examples of the engineering works of the world of different kinds, in such detail as our time will allow; and when we have done this, whether we do or do not attempt to formulate a definition that will describe the functions of the engineer of to-day and of the future, we shall, at any rate, realize and understand better what is the range, what are the kinds, and what is the character of the work which it is the business of the engineer to perform for his fellow-men.

Passing by the pyramids and the works of the Egyptians and of the Eastern nations, it will be worth our while to consider for a short time what was the character of the engineering work of ancient Rome. And, although the development of such work was very different at different periods of the long centuries during which Rome held her sway over the Old World, it will not be necessary for me to trace its various phases, for, inasmuch as the steam engine had not yet been thought of, it was not possible for advances to be made at such a rapid rate as that with which they are developed in our own times. Moreover, a consideration of the engineering work of ancient Rome gives us a conception of that of the whole civilized world as it then existed; for Rome carried her civilization and her engineering everywhere in the wake of her victorious arms.

Indeed, it was very largely to this cause that was due the firm grip that she acquired over the nations that she conquered. They found that their conquerors offered them a civilization more attractive than their own, and that Rome really took an interest in developing their countries, making good roads connecting them with herself, and sending her own engineers to aid them in making other roads and local improvements, besides encouraging them to develop their natural resources. The intimate connection into which they were thus brought with her led them to introduce such improvements as they found that the Romans possessed. Hence we find that Roman roads, Roman bridges, Roman aqueducts and Roman sewers spread to all parts of

Europe, and to all countries which came under her domination. Then when the days of corruption came and when she no longer chose to keep herself in the rank of the producers of the world, but sought to be fed by others without making any adequate return; when she no longer took pains to do thorough work, the Roman example of former times, which had already permeated the other countries of the Empire, still exercised its influence; and hence it is that some of the most lasting and best examples of Roman works were to be found in Gaul, in Spain and in Africa.

When we stop to consider how they managed to accomplish works of such magnitude and of such merit as they did with the small amount of facilities that they possessed, it seems truly wonderful. Imagine for a moment what would be the aspect of the world, and what the material welfare of our own land, if we were to annihilate the use of steam and of all the machinery that depends on steam engines to operate it.

And yet the Romans handled and transported enormous weights, which would even make us stop to consider how best to handle them.

When they had to carry some of their enormous monoliths long distances over land, they encased them in cylindrical wooden boxes, and rolled these boxes along the ground, drawing them by means of a very large number of horses; then, for lifting them, the means they possessed were tackle, rollers, screws and wedges.

Their stone-cutting had to be performed by manual labor, the use of fire and vinegar being only applicable to certain kinds of stone, and even then being hardly ever employed, and no other blasting compounds being known at that time. On their roads, however, were often to be found large numbers of tunnels cut wholly or partially through solid rock; some of their tunnels were of great length, as, for instance, the two tunnels at Posilipo, and also the emissary of Lake Fucino, the latter being a wonderful piece of engineering considering the facilities that they could command, notwithstanding its failure to accomplish its object. Moreover,

they often went so far as to dress the stone on the sides of their tunnels.

The Roman roads I shall not stop to describe, further than to say that, while, from our point of view, they were decidedly narrow, they were built with an amount of solidity that is surprising, and an amount of labor was expended upon them which is very creditable to their makers; moreover, the number and extent of these roads connecting all parts of the Empire with Rome was something enormous for those days.

While they knew and used most of the metals on a small scale, the principal materials employed in their engineering work were stone, bricks and cement, though some of their bridges were built of wood; and of course works of an intentionally temporary character were often constructed of timber.

On account of the difficulties of transportation the materials for building were obtained as near the place where they were to be used as possible; hence, when available, stone was derived from local sources, and this led to the establishment of quarries at a great many places all over the Empire, the quarrying being performed, however, by manual labor, with a very occasional use of fire and vinegar. For their larger works, their bricks were well burned; but the cost of fuel frequently led them to build houses of bricks dried in the sun. Next, as to cement: whenever they could find suitable materials near by, they used them, otherwise they secured it from further off. They had at Pozzuoli, near Naples, however, the source of supply whence they obtained their famous puzzolana, and this was sent wherever needed, being transported by water to the nearest point accessible by that means, and thence by land.

The Roman bridges and viaducts were either of wood or stone. In the case of the latter the full centre arch was almost exclusively used. When they could locate the foundations of their stone bridges on dry land, they built good and solid structures; but when they had to lay their foundations under water, they always had difficulty, and these were generally washed away in a short time, notwithstanding the variety

of expedients to which they had recourse. Hence we find that there were but few Roman bridges across wide streams, where foundations in the river were necessary, but they had no difficulty in crossing deep and narrow gorges where they could establish solid foundations for their work. They had no means of working under water, or of laying foundations under a considerable depth of water, and when they tried they did not succeed to make them sufficiently secure. Their aqueducts and sewers were fine specimens of engineering, considering the facilities they possessed. The water supply from different sources was kept separate, the purest being used for drinking. Their aqueducts were generally made of masonry or concrete, lined with a mixture of cement and brickdust polished smooth.

They carried these aqueducts across gorges or valleys, on stone bridges or viaducts, sometimes built of two or three rows of arches, one above the other, and this method they preferred to the use of siphons, though they had recourse to siphons at times, and, at times they employed a combination of the two methods. They also used settling tanks to clarify the water by allowing the impurities to deposit. Besides masonry conduits, they used lead pipes, but they had no pipes that could bear a very heavy pressure. They had no means of pumping, and hence the water had to be brought to the place where it was to be used by gravity. The sewers were, of course, a necessary consequence of the water supply, and these ran at one time under every street in Rome; but after the reconstruction of the streets by Nero, the lines of the streets did not always follow the lines of the sewers, and hence sewers often passed under the houses. The earlier sewers were constructed of cut stone, and so solidly were they built that the Cloaca Maxima can still be seen to-day, although the greater part of it is filled up with earth. The pitch of the sewers was small, however, and hence they were easily choked up. Moreover, a great many cities in different parts of the Empire were provided with systems of water supply and drainage.

Taking up next the ports and the waterways, we find that,

their boats being small, the works that they needed, and that they therefore executed, would not look large from our modern point of view; but, considering the times, some of them were magnificent pieces of engineering.

As to ports, when they could they built them in a river, erecting quays of stone or wood. They took advantage of the shelter afforded by natural features, and built protecting breakwaters when they needed them.

When they could reach dry land to build upon they always did so, but when not, they sunk large stones, or cradles filled with masonry, locating them by means of divers, or else they built dikes, and ran in liquid concrete, which, on solidifying, formed, as it were, a solid rock.

They had a great many ports all along the Mediterranean. They had, however, no efficient system of dredging, and their ports were always silting up.

Of course, their navigable rivers formed the natural commercial highways, as indeed they did everywhere before the introduction of railroads; hence, they carried out such improvements as they could, and such as were needed at the time, by removing obstructions from the river beds and by building sea walls.

They also built a large number of canals, some to connect two navigable rivers, some to connect a river with the sea, when the character of its mouth was such as to render it difficult for boats to enter in rough weather, and also to drain regions that were liable to be flooded in times of freshets. Apparently they were familiar with the use of sluice-gates, but not with the use of locks. Notwithstanding the fact that they had no efficient system of dredging, the canal built by Claudius and Trajan to connect the Tiber with the sea still forms the present northern branch of the Tiber's delta, although all the works long ago silted up; moreover, it served to provision Rome for four or five centuries. Similar canals were built in the case of a large number of other rivers emptying into the Mediterranean and the Adriatic. Other memorable canals constructed by the ancients were the various ones built from time to time to connect the Nile with the Red Sea, and the one connecting

the port of Alexandria with the Nile, which was planned by Alexander and executed by Ptolemy.

The Romans operated mines, not only in Italy, but also in various portions of the Empire. In Italy itself it is on record that there were gold mines in the valley of the Aosta, that there was galena in Tuscany, iron in Noricum, and that the Etruscans worked iron in Umbria and Brutium. Elba contained iron mines, and does now; and Sardinia, lead mines. A knowledge of mining, however, preceded the times of the Roman conquests, and mining operations were already under way in the conquered countries before the supremacy of Rome, but the Roman sway developed a greater activity in them.

Both Gaul and Spain were rich in mineral resources. The Romans, and also the Greeks, learned the metallurgical processes from the Egyptians and the races of the East. The Romans used gold in its native state, and hence it often contained silver, copper, or even iron. The enormous quantity of copper used by them would seem to indicate that they found native copper, or else carbonate of copper. Throughout France we find traces of old Roman iron works, in piles of slag and cinder, these works being at the mines, in consequence of the difficulties of transportation.

Their condition in regard to manufactures, especially in the earlier days, was so primitive as to be hardly worth speaking of.

Such is a very brief and cursory view of the state of engineering practice among the Romans. While we look with the profoundest respect and admiration at the works which they accomplished with the small means at their command, and while those who executed them deserve the highest meed of praise and all the honor that we can give them, nevertheless I would say to the pessimist who thinks that the world is always going from bad to worse, go and try living with such conveniences as were available in the old Roman times, the narrow streets, the uncomfortable houses, the lack of facilities for travelling, the great lack of conveniences as compared with what we possess to-day, and then see whether you will not appreciate the great boon

that all our modern civilization and industrial progress has conferred upon us.

They possessed nearly all the materials of Nature that we possess, but they had acquired very little control indeed over the great sources of power in Nature, and before they could make much further progress in their engineering work, they needed to be able to direct these for the use and convenience of man. This was what they specially lacked.

With the exception of the wind as used in sailing vessels, they may be said to have used muscular power of men or of animals for the accomplishment of all their work, and their history is a grand example of what man has been able to accomplish by the aid of little else in the way of power than muscular energy; but when they wanted to accomplish a very large task, they had to use a very large amount of this power; thus, in excavating the tunnel under Lake Fucino, it is said that 30,000 workmen were employed for eleven years.

In order to be able to make advances in material prosperity, and to surround himself with a larger supply of comforts and conveniences, man needed something more than muscular energy to aid him in his work. He needed to make the wind, the water, but more especially steam, his servants, and to secure the additional advantages of industrial progress which could never have been realized had it not been for the introduction of the steam engine, before he could pass from such works as those of the Romans to the magnificent engineering achievements of modern times. Indeed, we have in this old Roman work a very good example of what engineering science and enterprise was able to accomplish with practically no aid from machinery; and were I to trace, step by step, the progress of the world only in the kinds of work mentioned, viz., roads, bridges, ports, waterways, water supply and drainage, you would be forced to the conclusion that it was by the introduction of machinery, and of steam power to move that machinery, that every point of vantage was gained, and every advance was rendered possible. By way of illustration, we may note that two of the greatest difficulties which the Romans encountered

were due to not having the means of establishing secure foundations under water, and not having any such means of dredging as we have to-day. I shall not undertake, however, to trace the decadence of engineering practice through the dark ages, nor its subsequent rise, and the gradual steps through which it has reached its present condition, but shall pass at once to a study of engineering practice as it is to-day, and shall try, by means of a sufficient number of examples, covering, as far as may be, the different kinds of engineering work of modern times, to make plain what is the range and what are the characteristics of the work of the engineer to-day.

Probably the thought of engineering in the popular mind has been associated with what are often called Public Works more than with anything else; and especially with the means of transportation of passengers and freight, and hence with the means of facilitating, and, indeed, of rendering possible the commerce of the world, and also with water supply and drainage. These have often been classed as, and have often been, public works; although the fact is that works which have been carried on by the government at one time and in one country have been performed by private enterprise at another time and in another country. Moreover, at the present day the aggregate amount of engineering work demanded by private enterprise is much larger than that required by public works; but there was a time when the reverse was the case, partly because manufacturing and even mining, etc., were in their infancy, and were carried on on so small a scale that there was comparatively little opportunity for the exercise of engineering skill, whereas, public works were executed on a very extensive scale; and partly because, in the case of the old monarchical and despotic governments, it was only the government that was rich enough to carry out large works.

For present purposes, then, we will use the following classification of public works: roads, rail-roads, bridges, canals, improvements of rivers and of estuaries, lighthouses, water supply, drainage, irrigation. It is not my object to enumerate and describe the great works in these different

lines, but merely to make use of a few as illustrations of the character of some of the work of the engineer.

ROADS.

I ought not to pass this subject by without comment, especially in view of the fact that so much general interest is now being awakened in Massachusetts towards having better highways, and I do not doubt that the result of the movement will be that we shall eventually secure them. The very cause that led to the movement, and the movement itself, are added evidences that such work, if it is to be properly done, must be taken in hand by the engineer; and that we shall never have good roads as long as we leave the decision to each man who lives, or each town that is situated on the road, for this means leaving it to men who do not know what are the different methods of making roads, and what are the results that have followed the adoption of any one under certain conditions,—to men, in short, who do not know the experience of the past in that particular line. As to the engineering problems involved in building, maintaining and repairing a road, I shall only say a few words. In building a road there is always a certain amount of cutting and filling that has to be done; then there may be a variety of engineering problems involved according to circumstances. We may have to cut tunnels or half-tunnels in the side of a cliff, though we try to avoid this when we can. Then, if our road runs along the side of a hill or of a mountain, we may have to build stone walls for considerable distances to support the road on the lower side or to protect it on the upper side, and in these cases it is all-important to see that such walls are built properly, and have a secure foundation. We may also have to arrange such works as will carry off the water of any streams that flow down the side of the hill, and to see to it that these works are able to carry off all the water that will come at the time of freshets, so that the road may not be inundated. Along the Alpine roads we find a great many tunnels cut through the cliffs, and while the water that flows down the mountain side often passes downwards through a channel under the road, it sometimes passes over the cliff.

Probably the most important item to be attended to is thorough drainage, and whatever is necessary to secure it should, of course, be done; and the engineer should so construct it that neither the surface nor the subsoil shall retain water. The surface should not have any hollows which will retain water, and should have a slight pitch towards the drains. The engineer must then determine upon the kind of drains—whether they shall be open gutters, or closed conduits, or blind drains, according to circumstances; but whatever they are, they must be of sufficient capacity, and they must be kept open, and not allowed to become choked up; he must also determine where the drains shall deliver the water, and, of course, he must build whatever conduits are necessary. Next comes the construction of the road itself, whether it is to be a paved street or a macadamized road, and, if the first, what kind of paving shall be used; if it is to be macadamized, whether it shall have a paving beneath the metalling. His decision will be influenced by the nature of the subsoil, as well as other circumstances.

He has then to consider the strength and the wearing qualities of the materials that he is to use for paving or metalling. Then also the proper building of the road, including the consolidation of the material by means of the road roller. Then come the questions of what are the repairs that must be made in order to maintain the road in good condition. A great many other matters are liable to require attention, as the curbstones, the catch-basins, the sidewalks, etc. The engineer may have to erect road bridges, and these, of course, involve all the usual problems of designing and erecting bridges, including the proper foundations, etc., but I shall not stop to discuss these at present.

As to the amount of machinery that will be required, this depends upon the nature of the road. In some cases but little is needed, and in other cases a very considerable amount.

RAILROADS.

Let us consider next the engineering work required on our railroads, of which there are about 170,000 miles in the

United States, and which exert so large an influence upon the comfort and happiness of all the inhabitants of our country.

I shall not weary you with the story of George Stephenson's efforts, trials and triumphs when he built the famous *Rocket* for the Liverpool and Manchester Railroad in 1829, a story with which every schoolboy is familiar, but shall proceed to a consideration of what is some of the engineering work that has to be done in building, in equipping and in running a railroad.

We may adopt the following as a convenient classification of the different departments that involve engineering operations, viz.: (1) permanent way; (2) rolling stock; (3) stations; (4) signals; (5) bridges.

Permanent Way.—Beginning with the permanent way, there is first the location of the road, and this involves a very large number of questions that require careful judgment for their solution; of course, it is necessary to take into account primarily the amount of traffic that can be secured by any proposed route: at the same time due regard must be had to the expenses that will have to be incurred, both for first cost and also for operating the line; this, of course, introduces a consideration of the grades that will have to be surmounted, the curves that will have to be tolerated, the bridges that will have to be built, the excavations that will have to be made, the difficulties that are liable to present themselves in keeping the road in repair, sometimes the difficulties to be met with to keep it clear of snow, and a host of other considerations; then the actual work to be done in making the surveys, and fixing the location in a new country may involve a good deal of work, and a rather rough-and-tumble life. In America, instead of building the road up to the standard we should desire at the start, it is much more customary to build it poorly at first, and then make improvements as fast as money is earned with which to make them. So, in the first building of the road, the engineer may, to save expense, allow steeper grades and sharper curves than would perhaps be necessary if a little more expense were incurred, with the idea that

after the line has been in operation for a while, and has earned a sufficient amount of money to warrant it, the curves can be straightened out and the grades reduced; but he must see beforehand how this can be done. Leaving to one side for the present the matter of the bridges, we will assume that the road is located, and the permanent way is to be built. We have now, to a certain extent, a set of questions similar to those that arise in the case of common roads. There will be, of course, a great deal of cutting and filling. For taking out heavy cuttings we use steam shovels, one of which can do the work of 500 men, and when the embankment is made from earth thrown up from ditches on each side, ditching machines are used, some of which can throw up 3,000 cubic yards per day. In this case, just as in the case of a common road, we must see to it that the roadbed is thoroughly drained, and now, after the roadbed is made, we must put on a good layer of ballast of broken stone. This is the best, for it does not hold moisture. Moreover, that the ballast should be hard and well packed and should not hold moisture, are considerations of prime importance. On top of this ballast are placed the sleepers, which are carefully laid at the proper distance apart, and are so adjusted as to have an even bearing on the ballast; then their upper surfaces are dressed and the rails are laid down; then the roadbed is covered with gravel, which should be up to the tops of the sleepers, and then the chairs are placed and the rails are spiked down. Then the upper ballast or gravel is tamped in under the sleepers so as to cause them to have so thorough a bearing that they will receive the pressure of the rail equally. Now, besides the bridges on the road, there are a good many culverts, or small bridges that have to be built, where water drains off, and for other reasons. When they are to be permanent they are usually built of stone, but very often temporary ones are built of trestle work, and this is often supported on piles. Hence, we have use, so far, for steam shovels, ditching machines, pile drivers, and sometimes steam dredgers. Next, as to the rails; their weight has gradually increased from thirty-five pounds in the days of George Stephenson, to eighty, ninety and even 100 pounds

per yard at the present day. Moreover, while the first rails used were of wood, those of George Stephenson were of wrought iron, but now they are almost exclusively made of Bessemer or open-hearth steel; and this increase in the weight and the strength of the rails has been brought about of necessity in consequence of the increase in the weights of the locomotives from five or six tons for engines like the Rocket to fifty tons and more to-day. Another matter which the builder of a road in a settled country is liable to have to consider is the works needed to avoid grade crossings. Then in regard to tunnels, the American locomotive is so constructed that it can go around much sharper curves than the English or the European locomotive, and hence we can avoid tunnels much more easily than we otherwise could.

After the permanent way is established it requires constant and careful attention, as a variety of unforeseen accidents are liable to happen. Washouts may carry off bridges or culverts, wooden trestles may rot or take fire, rails may break, chairs may break or get loose, spikes may come out, landslides may occur in mountainous regions, obstructions may get on the track, collisions or accidents may occur. All these things must be guarded against by a most careful inspection, and when anything is found out of order, it should be repaired at once.

Then another matter that devolves on the inspection and repair gang is the following, viz.: the road, and hence the rail, is liable, through unequal settlement, to acquire an uneven upper surface, this occurring most frequently at the joints, and then not only is the riding made uncomfortable, but also there is more power required to draw the train than would be the case if the surface were even. Hence, it is a matter of importance, from the point of view of economy, to keep the roadbed in first-class condition.

Some roads have a dynamometer car which is primarily a car containing mechanism by which we can obtain a record of the pull on the draw-bar at any given instant, or for any given position of the train on the road. These cars are usually provided with another mechanism, which, whenever the car passes a hollow in the track, throws a little

paint on the side of the rail near the place. When a road has one of these dynamometer cars it generally uses it for this purpose, and then the trackmen find the paint and proceed to level up the track at that place. If it does not have a dynamometer car of its own, it often hires some one who has, to make the inspection. All these things require a large force to keep the permanent way in order, and it needs to be inspected constantly in all its parts. When, however, there is a break-down, it is often easier to bring men and material from some distant central depot than to try to get along with such appliances as can be found near by. It may be well to say that on our railroads there have been, and are still to be found, a large number of timber bridges, and that, doubtless, in the earlier days of the country, it would not have been possible for the roads to afford the money to build iron bridges; but that now steel bridges are the rule, and while timber is still used for temporary work, its use for permanent work in the way of railroad bridges is fast dying out.

Rolling Stock.—We next come to the rolling stock. As soon as the road becomes of considerable magnitude, the works connected with it have to be very extensive, and require a large amount of engineering work. One might imagine that when once the rolling stock is all purchased, if the road is small and not growing, and if the shops and buildings for the housing and the repair of the rolling stock are all built and equipped and in operation, that the looking after everything to keep it in proper order and repair, and the purchasing of the supplies needed, as coal, oil, etc., while it would involve the exercise of considerable executive ability, need not involve any considerable amount of engineering work; but as any one who carries on such work knows very well, the management of a business where so large an amount of machinery is concerned, necessarily involves a large number of engineering problems.

As examples, shops have to be enlarged or new ones built; new and improved or more powerful machinery has to be introduced, which may involve various rearrangements; alterations in some of the details of the running gear or

of some other portions of locomotives or cars; the providing of additional space for receiving coal, and of suitable arrangements and facilities for delivering it where needed; making suitable arrangements for keeping cars at such places as are needed on the road, so as to have them ready when and where they are needed; the establishing the necessary yards with the proper tracks and switches; establishing the necessary stationary boilers, pipes, etc., to heat the cars before starting; then comes the care of and the running of the shops, for any railroad, no matter how small, must have at least a repair shop, and, as in such a repair shop, the road must be prepared to make anew a considerable number of the parts of the locomotives and cars, the question always arises how far to go in manufacturing the parts new, and then how far to go in the matter of building, in whole or in part, new locomotives, and hence will arise all degrees of development in this regard, up to the point where the road manufactures all its own rolling stock, involving, in that case, a very large amount of engineering work.

Another matter that becomes of importance, as soon as the road is able to afford such a department, is a department of tests. This department usually has charge of tests of all kinds, including, of course, tests of oils and tests of the strength of materials, and any other tests which it may be deemed best for the road to make.

Thus, suppose that the road is considering the advisability of adopting some new kind of locomotive for a certain kind of service, and desires to know whether the change is liable to result in economy, especially in saving coal or not, it may be wise to have a series of comparative or even of absolute tests made to determine either its relative or its actual performance in regard to coal and water consumption. Or suppose the road is considering the advisability of making some change in the details of its locomotives or cars, and wishes to determine the effect of the change, as, for instance, in the brake gear, or in the manner of heating the cars, or in some arrangement for ventilating them, all such matters would come to the test department; besides

which, if the road is large, there will be enough chemical tests to keep at least one chemist busy, as tests of oils, of paints and varnishes, chemical tests of the materials used, etc. Then, of course, if new shops are to be built and equipped, there arises a variety of problems, first in regard to the foundations of the buildings, then as to the details of the buildings, their proper strength, heating, ventilation, light and adaptability to their purpose; their arrangement so as to require as little handling of the material as possible; the choice of the machinery to be used; its arrangement; whether there shall be much special machinery, and if so, what; the power plant; what kind of engines will be best to use under the circumstances of the case; how many there shall be, and where located; the laying out of the entire system of driving, including shafts, pulleys and belting or other modes of driving, if they are to be used; the steam boilers to be used; the erection of a suitable boiler house and chimney and its location; the foundry; the forge shop and its equipment, possibly including heavy steam hammers; the boiler shop, with all the necessary machinery, as plate-shearing, bending and planing machines, punching and drilling machines, hydraulic, steam or compressed air riveters, etc., besides the necessary cranes, etc., for handling the boilers in process of construction, as well as the establishing of suitable cranes or trolleys for handling the materials in all the shops in the best and easiest manner; the carpenter shop; the erecting shop for the locomotives. In the case of a number of large locomotive works, cranes are provided which can lift the entire locomotive and carry it from one part of the shop to another.

Then there is the building of the transfer tables, the building of the cars, with all the necessary appliances of brake pipes, heating pipes, lamps, couplers, seats, etc., the painting and varnishing of the cars and upholstering them, etc.

Then, in the case of very large railroad shops, the road might decide to make and roll its own steel, which would, of course, involve a complete furnace plant and rolling mill.

This course is followed by the London and Northwestern Railroad at Crewe, England, where they have a Bessemer plant with four converters, each of which is capable of turning out five tons of steel at one heat. The pig iron, which they buy elsewhere, is melted in a cupola furnace, and the melted metal is then carried by means of large ladles to the converters, which are vessels that can be turned over on their sides and back to an erect position, as they are mounted on trunnions. The converter is turned on its side, and the melted pig iron is poured from the ladle into the converter. Then a powerful blast is introduced, and the converter is turned back to an upright position, when combustion goes on violently, the oxygen of the air burning out the carbon of the pig iron. When this combustion has gone on for a suitable length of time, usually fifteen or twenty minutes, a determined amount of spiegeleisen, *i. e.*, an iron rich in carbon and in manganese, is mixed with the melted mass; then the converter is turned on its trunnions, and the liquid steel is poured into a ladle, whence it is run into the cast-iron ingot moulds, and is thus formed into ingots.

They also have an open hearth plant, with seven Siemens-Martin furnaces, *i. e.*, five twenty-ton, and two ten-ton furnaces. These are, of course, regenerative furnaces where the gas is made in gas producers situated elsewhere, and is brought to the furnaces through pipes laid under the ground. Then the gas on its passage to the furnace passes through a red-hot checkerwork of firebrick, while the blast is introduced after passing through another red-hot checkerwork; the combustion takes place in the furnace, where are placed the pig, the scrap, and other materials required ; and then, as the air and gas meet at a high temperature, combustion occurs and the carbon is burnt out of the melted mass ; then the hot gases pass out through two other checkerwork chambers to the chimney, thus heating up these chambers, so that the gas and air can be made to enter through them when the other two have become too cool. They have a rail-making plant of 45,000 tons annual capacity, and also a mill for making tires for locomotives and car wheels ; a mill for mak-

ing plates, and a mill for making merchant bars and other shapes which they may require. The steel from these rolling mills is then carried to the other shops, where it is to be used, on cars drawn by a small locomotive on a narrow gauge railroad which goes to all parts of the works.

It may be well to say a little more about these enormous works at Crewe, where the London and Northwestern Railroad can start from the raw material and make all parts of its locomotives and other machinery, except copper plates and brass tubes. These works not only make locomotives, but also all the signalling apparatus, and the signal cabins themselves, also cranes and other machinery, and even bricks, drain pipes, and also gas, besides which they have their own water works. The total area enclosed by the works is one hundred and sixteen acres, whereas the buildings cover thirty-six acres.

Of course, the shops where the locomotives are manufactured and repaired contain an enormous amount of machinery, and among the rest a considerable amount of special machinery. The steel plant is capable of turning out 5,000 tons of steel a year, and the total number of locomotives that have been made there up to May, 1890, was 3,135.

The greater portion of the parts of the locomotives of a given class which they build there are interchangeable, being made to standard sizes; so that if in an accident almost any one part of an engine is broken, another can be found in stock which will be suitable to put in its place and which will fit at once. There are about 6,500 men employed at these works, where about 2,000 engines a year are repaired, and where as many as 146 have been made in one year.

To establish and keep up this enormous place it has been necessary for the road to make provision for enabling its workmen to live there, as the town has practically been built up by the railroad. The company own about 850 houses, and they have built at their own expense a Mechanics' Institute and a church, and they have done a great deal to furnish to their employés and their families opportunities for improvement and amusement.

The cars are not made at Crewe, but at Wolverton, where

the works cover about fifty acres, and where they employ 2,200 workmen, and where they buy the wood in the form of logs, and again they have a narrow gauge railroad running to all parts of the works, and cranes of all sorts, so as to be able to handle the material and the work easily. The timber is sawed into planks or whatever form may be desired here, and then it is put into a drying room and seasoned, before it is used in building cars. The wheels are also made at Wolverton, these being wood wheels with steel tires, the wood being forced into the tires by hydraulic machinery. Then, of course, there is done here all the upholstering, painting, varnishing, etc. When we consider the extent and magnitude of these works, it is evident that there is the necessity for a very large amount of purely engineering work. The putting up of the buildings alone involves questions of adaptation of the arrangement to the greatest economy in handling, consistent with efficient working; adaptation of the form and proportions to the work to be done in them; questions of suitable foundations; questions of light; questions of strength of materials, especially considering the heavy loads that have to be borne in some of them; questions of chimney power, and of foundations for and stability of chimneys, of draught of chimneys, etc. Then besides this the road has to do all the engineering work for a large town and has to make provisions for a great deal that usually belongs to the town to provide, and not to a railroad corporation, thus it has to supply the town with water and gas, and all this means water works and gas works, and the solution of engineering problems that arise in connection with them.

Then it has not only to build its own shops but also houses in the town, hence it has to make brick

Then in order to make all the saving possible in labor, there is required a large amount of special machinery, and to design such, a man needs to be familiar with mechanism, and with the design of machinery, including questions as to its strength, its stiffness, and its proportions generally, as for instance, its bearing surfaces, etc.

Then need I say that the steam plant needs attention?

Are the engines and boilers, and their arrangement and running such as will ensure the greatest economy? Also the amount of coal and iron and other materials brought into these works must be something enormous, hence means must be provided for receiving them, for unloading them, and for storing them until they are needed.

Then, besides all these questions which involve a knowledge of mechanism, of strength of materials, and of steam engineering, etc., we have use for electricity in various ways. The first to present itself to one's mind in connection with a railroad will naturally be the signalling; but there are also other connections in which, if it is not much used yet, I do not doubt it will be ere long, viz: electric lighting, not only for the shops, but also for the cars, for although electric lighting of steam cars has not thus far progressed to the point where it is at all rivalling or likely to rival for some time the methods of lighting by gas or by oil; nevertheless, I believe that in course of time more progress will be made in this direction, and then we shall come to have our steam cars lighted by electricity; also in the use of electric brakes, which at present are employed only to a small extent; also in the use of electric cranes, which are the modern form of crane without any question. Indeed, electricity is gradually displacing other methods of driving cranes in our large shops and rolling mills and bridge works. By using it we avoid a great many clumsy methods of transmitting power, for the power has to be applied in such a way that the crane can be driven wherever it stands in its travel. An electric motor carried by the crane itself, with the connecting wires, furnishes an easy and neat method of transmission, and does not involve so much loss by friction. The application of electric motors to cranes will, in my opinion, be extended to a large extent to other machinery in our large machine shops and manufactories, and I believe it will not be many years before electric transmission of power will displace a great deal of the shafting and belting with which our shops are so much filled up at present.

Besides all this we have opportunities and the necessity

for a large amount of engineering knowledge and engineering work in the design and construction of the locomotive itself.

What are the conditions which we wish our locomotives to fulfill? They are to draw our trains at as high a speed as is consistent with safety, and to do this with the least expenditure for coal, for water, for repairs, etc., also to fulfill all the special conditions of the particular service which they are to perform, such as going around sharp curves, going up steep grades, hauling heavy trains, etc.

Of course, it is necessary that they should have the requisite strength and stiffness. Now, we have here at once questions of mechanism, questions of strength of materials, and questions of steam engine economy.

[*To be continued.*]

NOTE ON PEMBERTON'S METHOD OF PHOSPHORIC ACID DETERMINATION AS COMPARED WITH THE OFFICIAL METHODS.*

By Wm. C. Day and A. P. Bryant.

Having occasion to make a series of determinations of phosphoric acid in Florida phosphate rock, we have used the method recently described by Mr. H. Pemberton, Jr.,† and incidentally have made a number of comparisons between it and the official method. The following are the results:

GRAVIMETRIC DETERMINATIONS.

No. 1. From 0·7867 grms. $Na_2HPO_4 + 12H_2O$, obtained 0·2426 grms. $Mg_2P_2O_7$
No. 1. From 1·1100 grms. $Na_2HPO_4 + 12H_2O$, obtained 0·3433 grms. $Mg_2P_2O_7$
No. 2. From 1·0000 grams Florida rock, obtained 0·5828 grams $Mg_2P_2O_7$
No. 3. From 0·3807 grams Florida rock, obtained 0·0262 grams $Mg_2P_2O_7$
No. 3. From 0·4831 grams Florida rock, obtained 0·0333 grams $Mg_2P_2O_7$
No. 4. From 1·0036 grams Florida rock, obtained 0·0227 grams $Mg_2P_2O_7$

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* Read at the stated meeting of the Chemical Section, held February 20, 1894.

† *Jour. Frank. Inst.*, **136**, 362.

DETERMINATIONS BY PEMBERTON'S METHOD.

No. 1 used 1·0737 grams $Na_2HPO_4 + 12H_2O$ and 22·80 cubic centimeters KOH solution and 1·85 cubic centimeters acid.

No. 1 used 1·0370 grams $Na_2HPO_4 + 12H_2O$ and 21·30 cubic centimeters KOH solution and 0·80 cubic centimeter acid.

No. 2 used 1·0000 grams Florida rock and 41·85 cubic centimeters KOH and 5·05 cubic centimeters acid.

No. 3 used 1·0000 grams Florida rock and 7·55 cubic centimeters KOH and 3·10 cubic centimeters acid.

No. 4 used 1·0000 Florida rock and 6·75 cubic centimeters KOH and 5·50 cubic centimeters acid.

Strength of H_2SO_4 used 1 cubic centimeter = 0·015998 grams H_2SO_4.

Strength of potassium hydrate solution 1 cubic centimeter = 0·01847 KOH.

The percentages of P_2O_5, calculated from the foregoing determinations, are:

Substance.	*Gravimetric.*	*Pemberton.*
No. 1, sodium hydrogen phosphate, ...	19·72	19·73
No. 1, sodium hydrogen phosphate, ...	19·78	19·99
No. 2, Florida rock, ...	37·28	37·22
No. 3, Florida rock, ...	4·40	4·53
No. 3, Florida rock, ...	4·41	—
No. 4, Florida rock, ...	1·45	1·32

It is evident from the above figures that the agreement between the results of the two methods is as close as could be desired. Inasmuch as the Pemberton method is of extreme accuracy, is very easily carried out and effects a great saving of time and labor over the official method, it is well worthy of extended use. We have found that the author's statement of the time required for a single determination, namely, thirty to forty minutes from the time the solution is measured out for titration, is entirely reasonable. Omitting filtration of silica makes no difference in the accuracy of the results.

SWARTHMORE COLLEGE, PA.,
February 20, 1894.

BOOK NOTICES.

Encyclopédie Scientifique des Aide-Mémoire. Dirigée par M. Léaute, membre de l'Institut. Paris: Gauthier-Villars et fils et G. Masson. Collection de 300 volumes petit in-8. Chaque volume se vend séparément; broché 2 fr. 50; cartonné, 3 fcs.

Of this capital publication, which has received several previous notices in the *Journal*, we have received the following additional volumes of the series:

Bloch, Frédéric. Ingénieur des Manufactures de l'État. *Eau sous pression. Appareils producteurs d'eau sous pression.*

Launay (de). *Statistique de la production des gîtes métallifères.*

Widmann. Directeur général des Forges et Chantiers. *Principes de la machine à vapeur.*

Croneau, A. Ingénieur des Constructions navales, Professeur à l'École d'application du Génie maritime. *Construction du Navire.*

Gérard Lavergne. Ancien Elève de l'École Polytechnique, Ingénieur civil des Mines. *Les Turbines.*

Minel, P. Ingénieur des Constructions navales. *Introduction à l'Électricité industrielle. Potentiel. Flux de force. Grandeurs électriques.*

Minel, P. Ingénieur des Constructions navales. *Introduction à l'Électricité industrielle. Circuit magnétique. Induction Machines.*

We have nothing to add to our earlier favorable notice of this series, save the announcement that the later volumes fully bear out the fair promise of their predecessors. The fact that each of these volumes is complete in itself, constituting a concise summary of the state of the science or the art on which it bears, should make the series extremely popular. W.

Engineering Education Being the proceedings of Section E of the World's Engineering Congress, held in Chicago, July 31st to August 5, 1893. Published by the Society for the Promotion of Engineering Education, as Vol. I of their Proceedings. Edited by De Volson Wood, Ira O. Baker, J. B. Johnson, Committee, Columbia, Mo. E. W. Stevens, Printer. 1894.

This volume contains a portion of the papers read and discussed before Division E (Engineering Education) of the World's Engineering Congress, held in Chicago during the period of the World's Fair. The participants comprised many of the leading instructors in the engineering branches in the technical schools of the United States, and the themes presented and discussed were such as would properly suggest themselves to a body of professional teachers interested in the advancement of the standard of engineering education in our country. The papers may be read with much profit by all who are interested in technical education, and afford excellent evidence of the rapid progress made in this direction in recent years. W.

Les Moteurs à Gaz et à Pétrole. Par M. Gustave Richard, Ingénieur civil des Mines, etc. Paris: Vve. Ch. Dunod, Editeur, 40 Quai des Augustins. 1892.

The volume above entitled constitutes an exhaustive monograph on the subject of gas and petroleum engines, which mechanical engineers and others desiring access to a work going thoroughly into the questions of the theory and practice of this type of motor, should find of inestimable value. The work is issued in three parts, with an atlas of plates. The text also is profusely illustrated. The atlas, giving excellent sectional views of every important engine in this class, is incomparably better than anything yet published in the English language. W.

Sewage Purification in America. A description of the Municipal sewage purification plants in the United States and Canada. By M. M. Baker. With seventy-nine illustrations and an index. New York: *Engineering News* Publishing Company. 1893.

This volume is composed of a series of articles which originally appeared in the *Engineering News*, revised and classified for publication in book-form.

The subject is one of the first importance, and is attracting more and more attention every year from municipal authorities.

The literature relating to the subject could only be consulted heretofore by searching laboriously through municipal and other official reports, and the technical journals, widely scattered and difficult of access through the public libraries. The publishers of this series of papers, therefore, have done a real service to the engineering fraternity by collecting under one cover the more important data relating to the experience gained in sewage purification from the practice of some thirty municipalities in this country. W.

Journal of the Association of Engineering Societies. Vol. XIII, No. 1, January, 1894. Published monthly by the Board of Managers of the Association of Engineering Societies. John C. Trautwine, Jr., Secretary, Philadelphia. $3.00 per year, 30 cents per number.

The January impression of the Journal of the Association of Engineering Societies comes to us in a new dress, and exhibits other external and visible signs of improvement. Although the general features of internal arrangement have suffered no substantial change, evidences of careful and judicious editorial supervision are very apparent, as the result of Mr. Trautwine's painstaking and conscientious work. The co-operative feature of the Journal is a capital one, and is worth consideration by societies or associations having kindred objects, and which are individually not strong enough to maintain the cost of an independent publication. By co-operation this obstacle could readily be overcome and each would help the others while reaping the benefit of the work of all. The success of the publication of this Association, in this respect, is a conspicuous example of the benefit to be derived in this way. The Association is composed of the Engineering Societies of Boston, Chicago, Cleveland, Kansas City, Minneapolis, Montana, St. Louis, St. Paul and Wisconsin. W.

"*The Iron Founder*" *Supplement:* A complete illustrated exposition of the art of casting in iron, etc. By Simpson Bolland. Illustrated with over 200 engravings. First edition. 400 pp., 12mo. Cloth. $2.50. New York: John Wiley & Sons. 1893.

This volume is designed to supplement "The Iron Founder" of the same author, published several years ago, and which has had a cordial reception among those for whom it was written. "The Iron Founder" was devoted specially to the manipulations related directly to the daily practice of the moulder's art. The Supplement deals with matters bearing only indirectly on the work of the moulder, but which, nevertheless, it is to his advantage to know. The subjects treated of in the present volume embrace such matters as the erection and management of cupolas, reverberatory furnaces, blowers, dams, ladles, etc.; mixing cast iron; founding of chilled car wheels; malleable iron castings; foundry equipments and appliances; gear moulding machines; moulding machines; burning, chilling, softening; annealing; pouring and feeding; foundry materials; advanced moulding; measurement of castings; wrought iron, steel; the founding of statues, the art of taking casts, pattern modelling, etc.

From the foregoing summary, a fair idea will be obtained of the contents. The book is thoroughly practical in treatment, and will readily be comprehended by the foundry operative, to whom it is primarily addressed. The illustrations are numerous and most of them specially prepared for the book.

W.

Gas Lighting and Gas Fitting; including specifications and rules for gas piping, notes on the advantages of gas for cooking and heating, and useful hints to gas consumers. Second edition, rewritten and enlarged. By Wm. Paul Gerhard, C. E. New York: D. Van Nostrand Company, 23 Murray and 27 Warren Streets. 1894. Price, 50 cents.

This is the second edition of a very useful hand-book, forming No. 111 of the *Van Nostrand Science Series.* It is designed specially as a handy reference book for gas engineers, gas fitters, manufacturers of gas fixtures, dealers in gas appliances. Incidentally, it contains much information of a practical nature for gas consumers, architects and builders. W.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, April 18, 1894.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 18, 1894

MR. HENRY R. HEYL in the chair.

Present, sixty-five members and twelve visitors.

Additions to membership since last report, fifteen.

The Secretary announced the death of Mr. John Howard Gibson, a member of the Board of Managers, and reported that at its stated meeting, held on Wednesday, April 11th, the Board had taken suitable action in relation thereto, and had appointed a committee to prepare a memoir of the deceased for publication in the *Journal*. The Chairman, after an appropriate allusion to the loss which the Institute had sustained in the untimely death of one of its most active managers, directed that an election be held to fill the vacancy thus created in the Board.

The election resulted in the choice of Mr. Thomas P. Conard.

Mr. Clayton Beadle, of London, England, presented a paper describing some interesting newly-discovered cellulose derivatives, and products obtained therefrom, by methods devised and patented by Messrs. Cross, Bevan & Beadle, of London. Mr. A. D. Little, of Boston, supplemented the remarks of the previous speaker by giving an account of the properties of these products and of the various uses for which they were found adapted. The material, according to the manner of manipulating it, makes an excellent adhesive, taking the place of glue; it can be applied advantageously as a sizing in the manufacture of paper, in cotton goods, etc.; in massive form it can be moulded, pressed, turned, sawed, etc., and applied to the multifarious uses of hard rubber, vulcanized fibre, celluloid and similar products. It can be rolled into the form of plates or sheets of extreme thinness, the latter being almost transparent. It is capable of accepting various dyes, and of being mingled with mineral and other pigments. In these forms, the material may be made, by proper manipulation, to serve as floor covering, or leather substitute for bookbinders' and upholsterers' uses, etc.

A large number of specimens were shown, exhibiting various forms of these products and their applications.

Mr. F. E. Ives gave an interesting account of recent progress in the field of color photography, and described and exhibited the improved form of his photo-chromoscope, and a simple method of projecting photographic images on the screen in the colors of nature with the ordinary stereopticon.

The Secretary's report embraced a reference to the subject of the corrosion of gas and water pipes and underground electric cables from the effects of leakage of the return current of the electric trolley lines. The trouble

from this cause, the Secretary remarked, had grown to serious proportions in certain cities where the surface electric roads had been for some time in operation, notably in Brooklyn and Boston. He presented some extracts from a special report on the subject that had been made by the "Board of Commissioners of Electrical Subways" in Brooklyn, illustrating the same by the projection on the screen of views of a number of telephone cables, water and gas pipes, which had been dug up in Brooklyn, and all of which exhibited evidences of extensive corrosion, ranging from superficial pitting to complete perforation.

The Secretary gave a brief summary of the recent investigations of Dr. Engler upon the origin of petroleum. Dr. Engler had succeeded, by subjecting animal fats and fatty acids to distillation under high pressures, in converting about seventy per cent. of these products into petroleum hydrocarbons, obtaining in the operation ninety per cent. of the theoretical yield. These experiments appeared to demonstrate that the origin of petroleum is to be sought for in the transformation of the fatty portions of the animal remains abundantly found in the rock formations, in, or contiguous to which, petroleum occurs.

The Secretary described and exhibited the Falconnier blown-glass bricks, which have been used with very satisfactory results in the construction of conservatories, greenhouses, etc. These bricks are hollow and are blown in various shapes, and principally with ribbed or corrugated exteriors. They are very light and strong, and when laid together present an ornamental appearance. They permit of the transmission of an abundance of light; their corrugations serve to scatter the light and to avoid its concentration. They are hermetically sealed while hot, thereby preventing the entrance into them of dirt or moisture, and are annealed to increase their power of resistance. The laying of these bricks is said to be plain bricklayer's work, interposing no difficulties. The vaults are built up over a wooden centre, and the joints are made with lime mortar, or light cement mixed with fine sand.

Adjourned. WM. H. WAHL, *Secretary*.

JOURNAL

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OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXXXVII. JUNE, 1894. No. 6

The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the *Journal*.

CARBORUNDUM: A NEW ARTIFICIAL ABRASIVE MATERIAL.

[*Being the report of the Institute through its Committee on Science and the Arts on the invention of E. G. Acheson, of a new Artificial Abrasive Material.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 3, 1894.

The Franklin Institute of the State of Pennsylvania, for the Promotion of the Mechanic Arts, acting by its Committee on Science and the Arts, investigating the invention of Mr. E. G. Acheson, of Monongahela City, Pa., of an artificial crystalline carbonaceous substance, termed by the inventor, "carborundum:"

Finds that the invention is the subject of letters patent of the United States, No. 492,767, of February 28, 1893, granted to Edward G. Acheson, a copy of which accom-

panies this report* and may be referred to for descriptive and other details not herein incorporated.

The patent above referred to describes the manufacture of a crystalline compound, composed essentially of silicide of carbon, and embraces in its claims both the general method of manufacture and the product.

The primary object of the invention is stated to be the production of a carbonaceous material having properties which will render it useful as a substitute for diamond, bort, corundum and other abrasive materials.

Exterior view of electric furnace for making carborundum.

The method of manufacture consists in general in subjecting to an extremely high temperature, and for a considerable time, mixtures of carbon with silica or silicious materials and a suitable flux.

The inventor finds that the heat generated by an electric current affords him the most efficient conditions for securing the high temperatures needed to bring about the reac-

* Copy of this specification is filed with the record of the case.

tion, and accordingly states his preference for the use of the electric furnace.

The following general description will serve to explain the mode of operation. An intimate mixture of carbon and sand is introduced into a rectangular box of brick or fire-clay constituting the furnace chamber, the mixture being so placed as to surround a core of granular carbon. Into each end of the chamber project several rods of carbon making connection with the core, and through these rods and the core is passed a current sufficient in quantity and for a sufficient length of time to fuse the contained silica and bring about its subsequent combination with a portion of the carbon to form a new substance, a silicide of carbon, to which the name of carborundum has been given.

Upon removal from the furnace, the carborundum is found as a porous, cinder-like mass, formed of groups of small, glittering crystals of yellowish-green, bluish-green, or blue color, surrounded by more or less coherent masses of partly altered carbon.

The separation of the carborundum from the other constituents of the mass is first effected as completely as may be by hand. . The selected material is washed in water, then treated with acid to remove soluble impurities (iron, alumina, lime, etc.), again washed, then dried and crushed. By this means the individual crystals are separated, and the purified material is then separated into commercial sizes of different degrees of fineness by a process of floatation in a current of water, the several grades being thus automatically collected in separate receptacles.

An analysis of the product thus formed shows that it is a compound thus far new in chemistry, a combination of one atom of carbon with one atom of silicon, or, in chemical terms, a silicide of carbon, having the formula SiC.* The reaction involved consists in the withdrawal by the carbon of two atoms of oxygen from the silica of the sand or

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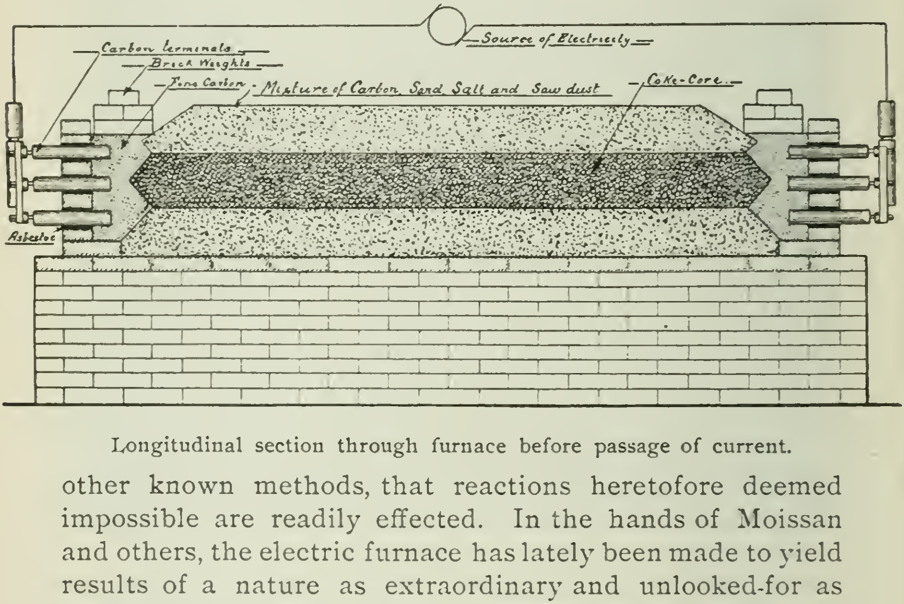
* For a very full and detailed account of the method of manufacture, the chemical and crystallographic properties of this compound, see this *Journal*, **136**, 194 *et seq.* Art. *Carborundum: its History, Manufacture and Uses*, by E. G. Acheson.

clay, and the combination of the nascent silicon with a portion of the surplus highly heated carbon, according to the equation,

$$SiO_2 + 3C = SiC + 2CO.$$

It is well known to chemists that the formation of a silicide of carbon by the direct reduction of silica with carbon has hitherto been impossible at any temperature attainable in the laboratory. By the employment of the heating effect of the electric arc in a furnace of the simple construction described above, in which the heat can be confined, the temperatures obtainable are so much greater than can be realized by any

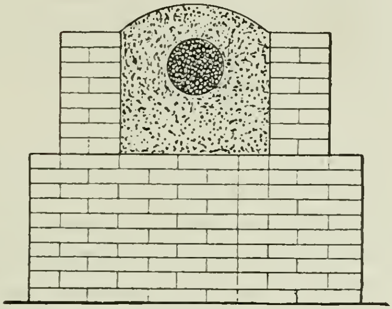


Longitudinal section through furnace before passage of current.

other known methods, that reactions heretofore deemed impossible are readily effected. In the hands of Moissan and others, the electric furnace has lately been made to yield results of a nature as extraordinary and unlooked-for as those which followed upon the first application by Davy of the voltaic battery to effect chemical decompositions. In employing the electric furnace method, therefore, to bring about the desired results, Mr. Acheson deserves the credit of having applied the only method by which it could have been successfully accomplished.

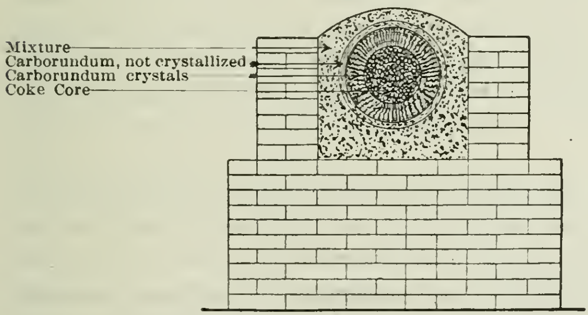
At this point it is worthy of notice that Moissan, whose recent experimental work with the electric furnace has greatly extended our knowledge of chemical reactions tak-

ing place at enormously high temperatures, produced this same compound (SiC) and described its properties in a communication presented to the French Academy at the session of October, 1893; also, that Schützenberger formed it by the combined reducing action of *carbon and silicon* on silica. Mr. Acheson's results were obtained and duly announced,


Section through furnace before passage of current.

however, before the publication, by these investigators, of their results.

The interest attaching to this compound, because of its novelty and the mode of its production, is greatly increased by the remarkable properties which it exhibits. Those



Section through furnace after passage of current.

properties which are more particularly referred to are the following:

Permanence.—Being formed at an enormously high temperature, it is natural to anticipate that it would be stable at all temperatures below that of its formation; but in addition to this stability, it appears to be capable of resisting

many of the most powerful chemical reagents. The only reagents that appear to be capable of decomposing it readily are the caustic and carbonated alkalies in the state of fusion.

Infusibility.—The substance appears to rank with the most infusible substances known, yielding only to the heat of the electric furnace.

Hardness.—In this quality, the substance approaches, if, indeed, it does not equal, the diamond, the hardest of known substances. This quality is one which, at first, would not readily be recognized, being masked by the brittleness of the crystals.

It is upon its hardness that the present and prospective applications of the material are based. It is, in brief, as an abrasive material, for grinding and polishing metals, glass and precious stones, that carborundum has been found to possess decided merits; and when its unique physical characteristics are so thoroughly understood that they may be utilized to the best advantage, the material, in all probability, will rank among the most valuable abrasives known to the arts. It was first usefully applied for the cutting and polishing of diamonds and other precious stones, and from reliable evidence presented in the course of this investigation, its cutting qualities will bear comparison with those of diamond dust. It is reported to be specially useful for polishing such gems, and one of the members of the subcommittee charged with this investigation, having tested the merits of the material on various gems, reports very favorably upon it.

It is used in considerable quantity in the grinding of the glass stoppers and bulbs of the new Westinghouse electric incandescent lamps, for which service it answers very satisfactorily. It is found very efficient in certain finishing operations in machine work, as, for example, for brass valve grinding. Of late, it has been introduced in the form of small wheels, discs and points for use in dentistry in place of the corundum tools in general use, and finally, it has just been introduced in the market in the form of wheels of large size for general grinding and cutting purposes in machine work as a substitute for emery wheels.

The sub-committee charged with this investigation was supplied with a considerable number of samples of the material, in powder form and made up into wheels, with which to make trial of its usefulness. The results are given in what follows:

A number of wheels of the sizes and grades indicated as most suitable for certain special uses were sent to a number of machine shops, whose proprietors had expressed their willingness to test them. (Their reports form part of the record of this case and are accessible for reference.)

The results of the tests of these large wheels were very contradictory, the wheels being pronounced very satisfactory by some, and being condemned by others, but in the main, the verdict was unfavorable. The absence of concordance in these results would seem to indicate the existence of faulty methods of manufacture, possibly the use of unsuitable binding material. It is certainly not unreasonable to assume that, when more experience has been gained with carborundum and its peculiar physical qualities are better understood, more uniform and better results may confidently be looked for.

The smaller wheels and points made for dentists' use were found to cut porcelain much faster than wheels of corundum and shellac of the corresponding sizes and grit, and to wear away more slowly than the latter. When used dry they cut faster than dry corundum wheels and do not glaze so readily as these. This quality makes their use cleanly for the operator.

The results of these practical trials may fairly be summarized in the statements that the new material possesses remarkable properties as an abrasive, being the first artificial substance thus far produced which compares favorably with bort in hardness and which is capable of being used as a substitute for it, that when its peculiarities are better understood it should be capable of yielding cutting wheels of high efficiency to take the place of abrasives in common use, and that should find general application in the arts wherever its price is not prohibitory.

In consideration of the facts set forth, the Institute

recommends the award of the John Scott Legacy Premium and Medal to Edward G. Acheson, for his discovery of a new and valuable artificial abrasive material.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, February 7, 1894.

JOSEPH M. WILSON, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by
ARTHUR BEARDSLEY, *Chairman.*

ON GAS BURNERS, GAS PRESSURE REGULATORS AND GOVERNOR BURNERS, GAS GLOBES AND GLOBE HOLDERS, AND GAS FIXTURES.

BY WM. PAUL GERHARD, C.E.,
Consulting Engineer for Sanitary Works, New York City.

[*Continued from p. 343.*]

II.—GAS PRESSURE REGULATORS.

It is a well-known fact that the gas pressure in the supply mains is constantly fluctuating, and that, at times and in certain districts, it is greatly in excess of what is required for proper combustion at the burners. Consumers are made aware of such excessive gas pressure by the roaring, hissing or singing gas flames, by irregularly shaped gas jets and cracked globes, by the jumping up of flames and other irregularities.

It is a popular fallacy that gas companies wilfully put on a high pressure at the works in order to make the consumers' meters go faster. A moment's reflection ought to convince any fair-minded person that this is not the case. If the above supposition were true, the gas companies would be the losers in two ways, viz.:

(1) A high pressure leads to a larger loss by leakage at the joints in the street mains, a loss usually estimated at

from seven to ten per cent. of the total gas output, but often largely in excess of this amount.

(2) An excessive pressure would mean an increased consumption, or rather waste, of gas in all street lamps having ungoverned burners and which are not supplied through a meter, but for which gas companies are paid a fixed sum per year.

It is, nevertheless, true that it is impracticable for gas companies to maintain a constant pressure in the street mains.

In a town of small extent, with absolutely level districts and with centrally located gas works, a gas pressure of $\frac{10}{10}$ inches of water would be ample to supply all consumers. Such conditions, however, are quite exceptional, and, as a rule, owing to variations in levels of various districts, owing to various diameters of the gas supply mains, owing to the unavoidable friction in the pipes and the extreme distances to which gas has to be conducted from the works, the gas works are obliged to put on a high pressure, in order to insure a sufficient supply to the most distant consumers and to those located in low-lying districts. Again, the pressure in the house pipes and at the burners changes with the varying number of burners lit at one time in a dwelling, and also, and much more so, with the varying consumption in a street or in a district. These unavoidable fluctuations of pressure range from $\frac{10}{10}$ to $\frac{40}{10}$ inches of water pressure.

The evils of high gas pressure have long been recognized, and efforts made to avoid the same. An excess of pressure at the gas burner means imperfect combustion, loss of illuminating power, vitiation of the atmosphere, blowing and hissing gas jets and a wasteful use of gas. In speaking of burners, I have already stated that a high pressure and small burners are not to be recommended; that on the contrary, ample volume of gas, issuing at a low pressure, from large burners, are desirable conditions for successful gas illumination.

The following results of experiments, taken from an able paper by Mr. Butterworth, the general manager of the

Columbus (O.) Gas Company, exhibit clearly the evil effect of over-pressure at the burner:

	Table I.					Table II.				
	Common 3-foot Burner Tip.					Common 5-foot Burner Tip.				
Pressure,	$\frac{10}{10}$	$\frac{15}{10}$	$\frac{20}{10}$	$\frac{25}{10}$	$\frac{30}{10}$	$\frac{10}{10}$	$\frac{15}{10}$	$\frac{20}{10}$	$\frac{25}{10}$	$\frac{30}{10}$
Consumption in cubic feet per hour,	5·70	7·55	9·15	10·40	11·45	7·45	9·70	11·50	13·15	14·20
Candle-power,	13·36	16·62	17·64	18·88	17·08	16·32	21·96	23·28	21·80	20·28
Candle-power per cubic foot of gas consumed,	2·344	2·201	1·917	1·815	1·492	2·191	2·264	2·025	1·658	1·428

These experiments demonstrate the enormous waste of gas occurring with common burners, where no attempt is made to regulate the pressure. They also show that high pressure means a loss in candle-power; for whereas the consumption of gas doubled, the efficiency of the burner decreased fifty-seven per cent. for the three-foot burner, and fifty-three per cent. for the five-foot burner, showing a slight advantage in favor of the larger burner.

There are various ways in which the gas pressure in the house pipes or at the burners may be controlled and checked. One rough method consists in throttling the main gas cock at the gas meter, and another in turning the gas keys at each fixture, *i. e.*, at the burners. Both methods, however, are unsatisfactory and unreliable, because the control of pressure is not automatic, and because it would obviously be impracticable to require the consumers to devote care, time and almost constant attention to the continual adjustment of the burner keys, made necessary by the constant fluctuations in the pressure.

A multitude of *check burners* have been devised, all having in view a retardation of the velocity with which gas escapes at the burners. This they accomplish to a certain extent, but as the obstructing material is, as a rule, fixed in the burner and cannot be adjusted, whereas the pressure fluctuates constantly, it is obvious that check burners cannot and do not attempt to regulate the flow of gas or govern the pressure. Even the best of check burners, having adjust-

able checks, would require a frequent adjustment during the evening hours and, therefore, would have no advantage over the simpler method of checking the flow by turning the gas keys. All that can really be said in favor of check burners is that they are better than the common gas burners and that they are somewhat cheaper than automatic governor burners. The Empire burner, the Young America, the Broenner, Leoni and Bray burners, Sugg's "Winsor" burner, Gregory's mica check burner and Silber's batswing burner, having a lower chamber in which the gas expands and thus escapes at the slit of the burner tip under diminished pressure, are examples of this class.

From Mr. Butterworth's paper I quote again two tests of consumption and efficiency, made with a five-foot Empire check burner and a No. 6 Bray special burner:

	Table III.					Table IV.				
	5-foot Empire Check Burner.					No. 6 Bray Special Burner.				
Pressure,	$\frac{10}{10}$	$\frac{15}{10}$	$\frac{20}{10}$	$\frac{25}{10}$	$\frac{30}{10}$	$\frac{10}{10}$	$\frac{15}{10}$	$\frac{20}{10}$	$\frac{25}{10}$	$\frac{30}{10}$
Consumption in cubic feet per hour,	3·10	4·05	4·85	5·50	6·05	6·10	7·75	9·10	10·25	bl'w'g
Candle-power,	9·24	12·44	15·18	16·74	18·04	15·60	18·56	20·74	22·72	—
Candle-power per cubic foot,	2·981	3·071	3·129	3·044	2·982	2·557	2·395	2·279	2·216	—

It is evident, from the above observations, that check burners do not prevent wasteful use of gas, that they do not control gas pressure and that the gas consumption of check burners necessarily varies with the pressure. In the above tests the consumption of the Empire burner was nearly doubled when the pressure increased from $\frac{10}{10}$ to $\frac{30}{10}$, whereas the candle-power per unit of gas consumption remained the same.

While the gas works may, by using station and district governors, reduce, or control to a certain extent, the pressure in the street mains, it is obviously desirable that the consumers should use means in their houses for controlling the gas pressure automatically. Gas companies long ago recognized the evils of excessive pressure, and also the fact

that economy in lighting depends upon its efficient control. Where they undertake to furnish public illumination of streets and squares by contract with the city for a stated fixed annual sum of money for each street lamp, they therefore, applied to the burners automatic means for controlling the pressure and thus preventing waste of gas.

Two entirely different methods may be adopted by the consumer to effect an automatic control of the gas pressure. He may apply an automatic gas governor on the house service pipe at the meter, which regulates and reduces the pressure in the whole house pipe system, or else he may use automatic gas governor burners, which control the volume of gas supplied to each light separately, establishing a constant consumption at each burner, while leaving the full pressure in the house pipes.

There are a large number of *gas pressure regulators* in the market, and as it is the chief object of this paper to point out to the consumer that there are means available for efficient control of the gas pressure, rather than to offer a detailed description of these devices, many of which are quite similar in principle and in construction, I will simply state that there are two kinds of pressure regulators, namely, the dry and the wet regulators, the former using a leather diaphragm, whereas the latter use a float, cup or bell, dipping either in glycerine or else in mercury.

The Sugg diaphragm pressure regulator and Peebles' diaphragm regulator are examples of English devices of the first class, whereas the Stott, Shaw, Sugg, Bower, Ewart, Brown's "Excelsior" and Peebles' mercury, are English pressure regulators belonging to the second class.

The "National" automatic and the Amick gas regulators are American liquid governors, having a brass globe floating in a seal of glycerine, and the Beattie, O'Gorman and Patterson regulators are examples of American mercury seal regulators. Some of these are obtainable for sale, whereas others are only placed on rental in the houses of consumers by companies obtaining a revenue from the saving effected, as shown by the monthly gas bills.

It is an essential condition, where pressure regulators

are applied, that the house pipes should be very ample in size, that there are as few elbows or bends in the pipes as possible, and that the tubing of gas fixtures, the aperture of gas keys and the slits of the burners are large; in other words, that the volume of gas supplied to the burners is ample, otherwise the inevitable result of a control of pressure is a paucity of light. Therefore, such pressure regulators should never be used by consumers where the above conditions are not complied with, otherwise the remedy might prove worse than the evil complained of. It is equally useless to apply pressure regulators to houses in low-lying districts where the pressure is already low. In all cases the saving in gas consumption, which is the result of a reduction in gas pressure, should be effected without any loss of illuminating power.

A pressure regulator placed on the service pipe of a house reduces an excessive gas pressure and secures a tolerable uniformity of pressure and supply at all burners; but this is only true of buildings with small floor area and of few stories in height. For large factories and halls with many lights on the same level, where the whole number is always lighted, a pressure regulator will answer. In the case of large buildings and in all buildings of many stories, on the other hand, an absolutely uniform pressure is not attained, because no matter how well the distribution pipe system has been calculated and arranged, there is necessarily some loss of pressure through friction in long pipes and at elbows, so that the gas at burners situated at a distance flows at a lower pressure. Owing to its specific gravity, which is not quite one-half that of air, gas tends to gain in pressure with increased elevation, each rise of ten feet vertically adding one-tenth inch of water pressure. This explains why, in high buildings, even with a pressure regulator at the meter, the gas pressure increases for each floor, causing the burners in upper stories to "blow." Therefore, the better method in such cases is to provide a governor on each floor.

It is sometimes feasible in cases where the number of burners lighted remains constant, and where the pressure

varies only slightly, to control and reduce the pressure on each floor level by a governor, and in addition to use a good check burner at the fixtures. Sugg's "Winsor" screw regulating burner has been devised with this special object in view.

The best and surest remedy, undoubtedly, consists in the use of automatic acting *governor burners* at all fixtures. Governor burners must not be confounded with check burners, which only retard, whereas governor burners regulate, the flow of gas in such a way that, as the pressure increases, their regulating action increases and *vice versa*. Such governor burners cause the gas to issue at the burner in a constant volume, no matter what the pressure in the service pipe is, hence the name "Volumetric" burners is sometimes applied to them.

The first automatic regulating burners were devised for street lamps, and they were sometimes very clumsy in shape, casting large shadows downwards. They have been much improved of late years, and now there are several good governor burners obtainable which are compact in shape and which act almost perfectly in regulating the supply to the burners, and in preventing gas from flowing out under excessive pressure. Even governor burners, however, may in time clog up, and will require occasional cleaning.

There are many different makes of volumetric burners, and it is not my intention to describe any of them in detail. Briefly stated, the flow of gas is controlled in them by a light cup, cone or disc, placed in an enlarged chamber of the burner, which floats up or down as gas pressure increases or diminishes, and being connected with a valve at the entrance to the burner, it opens or closes the same, and thus causes more gas to be admitted when the pressure fails, and when the pressure rises it reduces the supply.

Volumetric governor burners are equally applicable to flat-flame, round-flame, regenerative and incandescent burners. The best regenerative lamps are always fitted up with such a regulator, and likewise are the Argand and flat-flame burner lamps of the highest make always sold with them.

Among the best-known governor burners I mention those

of Giroud, Wilder, Sugg, Peebles and Lux, the first one being a French burner, the second a burner of American make, the third of English, the fourth of Scotch make, and the last one being a German volumetric burner.

Other burners, not so well known or extensively used, are the Rappleye rheometric governor burner, endorsed in 1882 by the Committee on Science and Arts of the Franklin Institute; the Champion burner, patented by Van Wies in 1890; the Chamberlain, Boore and Jackson burners, all of American make; the Schuelke adjustable gas governor burner, of German make, and the Orme, Hawkins and Acme burners, of English make, the Hawkins burner being the only governor burner with union jet tip known to me.

My list does not pretend to be exhaustive, and it is quite possible that I may have unintentionally omitted some good burners which have not come to my notice.

The Wilder volumetric governor burner is the invention of Moses G. Wilder, M.E., of Philadelphia, who obtained a patent for it in 1880. This burner is a good example of an American governor burner, and it is suitable not only for flat-flame and Argand burners, but also for regenerative lamps and for the Welsbach incandescent light. The maker, in describing it, states that it is not a pressure reducer or regulator, that the flow of gas through it is not changed by very wide variations of pressure, and that it secures a uniform rate of supply to the burner, with little or no reduction of pressure.

The inventor of the Boore burner, Mr. Lewis Boore, of Buffalo, N. Y., states that he endeavored to produce a reliable and simple automatic governor burner of low cost, which would indicate practically correctly for a very wide range of pressure, without having such an extreme accuracy or such close adjustment as to destroy its utility.

Wm. Sugg & Co. make two kinds of volumetric burners, a steatite float governor and a leather diaphragm governor burner.

Sugg's patent "Alexandra" governor burners combine great economy with efficiency, and produce a brilliant, white, silent light. They are fitted with steatite float governor,

and the superior light attained is also a result of adopting double annealed Albatrine globes with wide opening. An even better flat-flame burner by the same maker is Sugg's patent "Christiania" governor burner, fitted with a specially prepared leather diaphragm governor, with Sugg's patent table top circular slit steatite burner tip. Sugg's London improved Argand burner always has a governor burner attached to the fixture.

Mr. Wilder calls attention to the fact that his governor burner, to operate well, requires a full street pressure. This rule is applicable to all volumetric burners; hence, where these are used, a pressure regulator should not be used at the meter.

In order to show, by actual experiments, how nearly uniform the consumption of gas remains with governor burners, I refer the reader again to Mr. Butterworth's able paper on governor burners, wherein is published the following table, showing the gas consumption of a number of such burners under varying pressures:

TABLE V.

Pressure,	$\frac{10}{10}$	$\frac{15}{10}$	$\frac{20}{10}$	$\frac{25}{10}$	$\frac{30}{10}$	$\frac{35}{10}$	$\frac{40}{10}$
	cu. ft. per hr.	*cu. ft. per hr.*	*cu. ft. per hr.*	*cu. ft. per hr.*	*cu. ft. per hr.*	*cu. ft. per hr.*	*cu. ft. per hr.*
Six-foot governor burner,	6·20	6·20	6·35	6·30	6·25	6·25	6·40
Six-foot governor burner,	5·95	6·50	6·20	6·20	6·05	6·15	6·05
Five-foot governor burner,	4·50	4·50	4·55	4·55	4·65	4·65	4·60
Five-foot governor burner,	4·50	4·65	4·55	4·65	4·70	4·65	4·55
Five-foot governor burner,	4·90	4·95	4·95	4·95	4·90	4·90	4·90
Adjustable burner,	5·60	5·50	5·40	5·30	5·07	4·80	4·60
Adjustable burner,	4·96	5·97	6·21	6·19	6·05	5·89	5 69
Adjustable burner,	4·95	4·95	4·95	4·95	4·95	4·95	4·95

The last burner in the table showed a perfect uniformity of supply under the wide range of pressures used in the test. Some of these governor burners are adjustable, and if they are required to pass a certain quantity of gas per hour, a nice adjustment is necessary, which can only be accomplished if the candle power and quality of gas, its pressure and specific gravity are known. A governor burner adjusted for a gas of certain specific gravity would not remain correct for a gas of different density, or for any temperature which would change the density.

Both, the pressure regulators on the main service pipe and the governor burners, accomplish a saving in gas consumption by preventing useless waste, amounting to a reduction of from twenty to forty per cent. in the gas bills. Other incidental advantages gained are: a great improvement in the steadiness of a gas flame without regard to the number of burners lit or the constantly changing street pressure; the hissing or roaring noise, the blowing, and the flickering of lights is prevented; the illumination becomes stronger; the smoking of Argand burners is prevented, and the air of the room is vitiated to a much smaller extent by the products of imperfect combustion. With governor burners, however, these results are attained in a higher degree than with pressure regulators on the service pipe.

To sum up, practical considerations must decide which form of regulation it is best to adopt. In this connection the following rules are to be recommended, viz.:

(*a*) Where the street mains are large and the differences of level insignificant, use either check burners or volumetric burners.

(*b*) Where the street mains are small, or the pressure is low or the house pipe insufficient, neither method of regulation should be employed.

(*c*) Where the town is hilly and there are considerable differences of elevation in the districts, a pressure regulator will answer, provided the house pipes are large, the gas keys full bore, and the building only a few stories in height, and not of great extent laterally.

(*d*) Where in such districts the buildings are high or very large, a pressure regulator on each floor should be used, together with regulating check burners at the fixtures, but in such cases governor burners are a simpler remedy, and are, therefore, to be preferred.

III.—GLASS GLOBES AND GLOBE HOLDERS.

Flat-flame burners are, as a rule, surrounded with glass globes, and practical experience and observation have established the fact that if these are unsuitably arranged or of improper shape, they constitute another factor, caus-

ing deficient illumination, imperfect combustion, and frequently a waste of gas and a corresponding increase in the gas bills.

Gas globes are used chiefly to protect open flames against draught, and thereby to prevent the annoying unsteadiness and flickering of lights. They are also employed to shade the eyes from the direct glare of the light, to diffuse and soften the light, also to add to the good external appearance of gas fixtures; and finally, gas globes are, for safety's sake, placed over naked lights to shield the flame from coming into direct contact with inflammable materials. From all of which it follows that gas globes are used for utility even more than for ornament, hence their design and construction should be based on sound principles.

In order to obtain good illumination, and to avoid the flickering of gas lights, the air necessary for combustion should be brought to the flame in a slow, uniform and steady current. If the air supply is insufficient a flame is apt to smoke and will blacken ceilings and contaminate the air. If the air rushes to the flame in a violent manner, this will destroy the steadiness of the light, the light will flicker and jump, and it has the further detrimental effect of cooling the flame, and thereby reducing its brilliancy.

The old style glass globes were quite defective in shape, form and material. They were made with very narrow top and bottom openings, or if tulip-shaped and widening at the top, the bottom opening was extremely narrow, being often but one and one-half or two inches in diameter, and, where such globes were in use, the ceiling was often the only well-illuminated place. The result was that, owing to the smallness of the bottom aperture, the contracted globe acted like a chimney, causing the air current to impinge upon the flame to such an extent as to seriously disturb the flame, and thereby causing same to flicker in a distressing manner. Another defect of the old style globes is that they form dust traps, and that they are readily soiled in lighting.

If, added to this defect in the globes, the gas pressure at the burner was excessive, the resulting illumination necessarily was very imperfect. To determine the actual loss of

light due to small openings in globes, Dr. Wallace made a series of experiments, which showed the following results:

A naked flame was tested and found to give 16·8 candle light. The same flame, surrounded with a seven and one-half inch diameter clear globe, with two and three-eighth inch bottom opening, gave 15·4 candle lights, or loss of 8·3 per cent. The same flame, surrounded with a seven and one-half inch diameter clear globe, with two and one-quarter bottom opening gave 15·2 candle light, or loss of 9·5 per cent. The same flame, surrounded with a seven and one-half inch diameter clear globe, with two inch bottom opening, gave 13·6 candle light, or loss of nineteen per cent. The same flame, surrounded with a seven and one-half inch diameter clear globe, with one and one-half inch bottom opening gave 13· candle light, or loss of twenty-two per cent. The same flame, surrounded with a seven and one-half inch diameter clear globe, with one inch bottom opening, gave 12· candle light, or loss of 28·6 per cent.

All glass globes, moreover, absorb a certain amount of light, and the loss of light and corresponding waste of gas due to this cause increases the more opaque the glass globe is. Fancy "ruby" or other colored, etched or otherwise decorated globes in particular obstruct a large amount of light, and hence increase gas bills by the necessity of keeping a larger number of lights burning on a chandelier. It is stated on good authority that light is obstructed as follows:

	Per cent.
By clear glass globes,	10·15
By slightly ground globes,	24
By globes ground all over,	25·40
By opal thick glass globes,	35·60
By colored or painted globes,	64

Lastly, the globes with narrow bottom and wide top opening are objectionable, because instead of casting light outward and downward by reflection, they throw the greatest amount of light up to the ceiling, where it is not wanted.

It matters little how attractive in shape and artistic in outline such old style globes are; as long as they tend to disturb the flame they are clearly objectionable. These defects have been gradually recognized, and such globes

with contracted openings happily are now being discarded. The new form of globes has wide bottom openings, which admit the air without causing a draft; the shape of the globe is designed more with a due regard to its proper functions than solely from a decorative point of view. Such globes induce a straight, upward, gentle current of air, and the flame remains steady and bright. All globes of modern construction have bottom openings four and five inches in diameter, and have the incidental advantage that a portion of the light falls directly downward without being obstructed.

The Sugg "Alexandra" and "Christiania" burners are surrounded with globes of most desirable shape and material; the Broenner burners have similarly shaped "Cornelian" globes; and Wilder, in the description of his volumetric burner, recommends globes four and one-half inches in diameter at the bottom and five and one-half inches at the top.

Regarding the material for globes, clear crystal glass is the best, because it absorbs the least light. Still, it oftentimes becomes desirable to render the light of a gas flame soft and mellow, and for such cases thin milk-white opal globes are best and quite effective. Sugg uses with his best flat flame governor burners double annealed large size globes, with wide bottom opening, which he calls "Albatrine" globes, and which give a particular softness to the light. The cheaper kind of thick opaque white glass globes should be avoided, as they intercept as much as seventy to eighty per cent. of light.

In connection with globes, it is noteworthy that somewhat increased illumination is obtained by using globe holders which are as little light obstructing as possible, *i. e.*, very thin sheet brass or brass wire globe holders. The old style fixtures had heavy and cumbrous cast brass holders, or heavy discs, triangles or rings, all of which are objectionable, because they intercept a portion of the light, and cast a shadow downward and thereby cause a loss of light. The new shadowless globe holders, made of three simple prongs of brass wire, not more than one-eighth of an inch thick, and

without any rims whatever, are recommended by all dealers in advanced gas light fixtures.

Lastly, the position of the glass globe in reference to the gas flame is of a good deal of importance where it is desired to secure a steady, bright light. It has been found long ago, by experiment, that by arranging a shadowless globe holder on the burner in such a manner as to place the level of the bottom of the flame in line with the bottom edge of the globe, the flame will burn very quietly and steadily, and will not be affected much, if any, by the ascending air current, whereas if the flame is set higher it is apt to flicker.

This correct position and shape of a glass globe has been pointed out repeatedly by such gas engineers as Wilder, Peebles, Sugg, Broenner, Silber and others, in connection with their gas burning appliances; but on the whole, in practice, little attention has been paid to this simple yet efficient rule.

[*To be concluded.*]

EMERY AND OTHER ABRASIVES.*

By T. Dunkin Paret,
President of the Tanite Company.

[*Concluded from p. 372.*]

While small specimens of corundum, in the form of imperfect sapphires, have come from Montana, where the existence of this mineral has long been known, no other locality has yielded corundum except that well-known belt which reaches from Massachusetts to Georgia, and which seems to have its center in the corner where North and South Carolina, Georgia and Tennessee come together. In this belt the localities where corundum occurs are innumerable, but the prevalence of the mineral is a poor indication of its quantity. Corundum occurs in pockets, seams, sand veins, narrow streaks and detached crystals, seldom in large mass. Chester County, Pa., is, apparently, the only locality where large solid masses have been found. The

largest annual product of American corundum has been 645 tons, and, though corundum mining companies have multiplied rapidly during the last few years, the commercial supply has never been more precarious.

Unlike corundum, emery consolidates in large masses. It does not, indeed, form continuous beds of great extent, like coal or iron, but its discontinuous masses and veins sometimes contain hundreds of tons. The emery-bearing locality in Westchester County, N. Y., is a strip from one-half to three-fourths of a mile in width, and from five to six miles in length. The geology of this district and the occurrence of emery in it might be described in almost the same language as that which Dr. Smith applies to the celebrated emery district near Ephesus in Asia Minor.

Dr. Smith* says "all the rocks of the surrounding country appear to belong to the old series; the limestone is entirely devoid of fossils and metamorphic in character; it rests on the older schists of which mica schist appears the most abundant; and this again farther to the north was traced in contact with gneiss. The limestone is of a light blue passing into coarse-grained marble." "The place, however, to which it is traced in greatest abundance, is on a part of the summit about three miles from the village of Gumuch, and some 1,500 to 2,000 feet above the level of the valley; it overlooks the magnificent plain of the Miandre, whose curiously tortuous course is seen as if traced on a map. The emery lies scattered on the surface * * * in angular fragments of a dark color, and large masses of several tons weight are seen projecting above the surface; in penetrating the soil, the emery is found embedded in it and a little further down it is come to in the rock." "Some times the emery forms a solid mass several yards in length and breadth."

In describing the Westchester County emery beds, we would say that the place in which the largest number of openings have been made, and which has excited the most interest, is on a part of the summit about three miles from

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* *Am. Jour. Sci. and Arts.* **2**, x, 356.

the town of Peekskill, and about 700 to 800 feet above tide level. It overlooks on the one side, the valley of the Croton, whose stream is invisible, and on the other side, the Hudson, whose distant waters look like some lake in a painting. On the north and northeast of the emery belt are outcrops of granite. South of it lies the common marble of Sing Sing—still further south, at Spuyten Duyvil, occur the oldest of the Laurentian gneisses, and still further south, on Manhattan Island, the mica schist. The emery is, however, all immediately associated with a hornblende rock. Large masses of emery are seen projecting above the surface. These are delusive, and those which hold out a large promise are sometimes found to extend only one or two feet underground and to yield only five to twenty tons. Such masses are usually surrounded by soft, reddish earth.

Dr. Smith says of the Turkish locality, "the earth in the neighborhood of the blocks of emery is almost always of a red color, and serves as an indication to those who are in search of the mineral." In Westchester, the red earth is not an indication, for there is within the emery belt an iron-bearing rock which decomposes very rapidly and forms a red earth, while there is no emery associated with it. There is no sign of fracture in these discontinuous masses of moderate size, and they occur on the very tops of hills and under such circumstances as to indicate that they are not boulders and have not broken down from higher cliffs. As in Turkey, so also here, "in penetrating the soil, the emery is found embedded in it, and a little further down it is come to in the rock." Small fragments turned up by the plow in cultivated fields are sometimes the first indications. Search in their neighborhood reveals other fragments embedded in the earth, and near these and lower is found the rock. Sometimes this only approaches the surface and forms such a small point that it might lie undiscovered for years. In one place discovery on the surface of a very fine grained, pure block, weighing about 200 pounds, stimulated search which was continued at intervals, fruitlessly, for several years. Other varieties were discovered, but no sample like the original. Several blasts were made within a few feet of the nar-

row point which just fell short of reaching the surface, and yet did not disclose it. A lucky blast uncovered it, and over 100 tons of uniform quality were taken out, leaving it far from exhausted. As in Turkey, so also here, "the emery lies scattered on the surface * * * in angular fragments of a dark color," but at this point my description must differ from that of Dr. Smith. He says: "in no place does it present anything like a vein, nor has it signs of stratification." I find, in Westchester, that the angular pieces generally indicate veins. Such veins are distinct and numerous. The regularity with which they thin out at the edges and thicken at the centre suggests true lenticular beds, though there are, of course, exceptions to the rule. The quite regular recurrence of seams separated, but parallel, strongly suggests stratification. These seams occur in the solid rock and the emery breaks freely from it, it being a most unusual thing to find any adherence of the top or bed rock.

Emery from veins breaks easily, with flat sides and sharp angles. These sides, when dry, often seem painted, so bright are they with yellow and red, and sometimes they take on an almost iridescent tint, with sheen of pink and green. Strangely enough, large amorphous masses are sometimes found, disconnected from rock, and lying between the regular veins. These amorphous masses, whether they be small or large, present no angular outlines, and do not break up in such flat-sided pieces as do the seams. It should be noted that the angularity of the vein emery is not due to its being freshly mined. The broken-down edges of veins, found in fragments on the hill-sides far below the veins, and which have weathered for hundreds or thousands of years, seem as sharp and unaltered as those freshly broken. The amorphous masses, on the other hand, are so destitute of cleavage that continued use of a heavy sledge hammer only batters them into shapeless pieces. The emery in each vein is of comparatively uniform quality though differences can sometimes be detected in blocks lying side by side. That in the amorphous masses varies far more. One such mass, of yet unascertained quality, I

estimate, by a rough calculation of its cubic contents, to contain from 500 to 700 tons. This mass was jokingly christened by the miners as "Knight's bonanza." It was of a light grayish color, not markedly different from the top and bed rock, from which it stood out almost separately on all sides, and like those rocks, was covered with gray moss. The owner decided that all the rock was alike and estimated that there were hundreds of thousands of tons.

The emery of this district presents easily discernible differences. Some is coarse grained, some fine, some black and shiny, some gray. Some is uniform in color, some distinctly streaked.

This deposit was described about twenty years ago by Dr. J. P. Kimball, and his classification agrees with my own. He describes two classes as "granular, massive, resinous," giving a slightly different analysis for each. I should say one coarse and one fine. A third he describes as a "banded variety, gray in general color, and sparkling, from the presence of a micaceous mineral." A fourth, as a "quartzose variety, gray and sparkling, like number three but without a banded or gneissic structure."

Inasmuch as the "Emery Manufacturers' Association" has issued a circular referring to the product of these mines as "a spurious article of emery," and referring to its ore as "inferior or comparatively worthless stone," the opinion of Dr. Kimball is worth consideration. It deserves additional weight because his investigation had no reference whatever to the use of this ore as an abrasive. It was solely with the view of its use in iron metallurgy that his study was made. The analyses he refers to were made by Dr. C. F. Chandler and Mr. F. A. Cairns. Dr. Kimball says, "The above analyses, together with the physical and mineralogical features of this material, serve to identify its character as a mixture of corundum with magnetite, slightly titaniferous, as usual, when thus associated, analogous to the emery of Chester, Mass., and its proportions bearing a still closer resemblance to specimens obtained by Dr. Genth, from the Goldboro ore belt of North Carolina in 1871, and analyzed by that chemist." Dr. Kimball's article is entitled

"Emery and its Uses in Iron Metallurgy," and throughout this lengthened essay he always refers to the Westchester ores as emery. It is an admitted fact that the percentage of alumina in these ores is less than that in the Greek and Turkish samples analyzed by Dr. Smith, but I have already shown that the effective hardness of Dr. Smith's samples was not proportioned to the percentage of alumina. I have also shown that American corundum has been sold at the highest price commanded by a genuine article, though its percentage of alumina was much less than that contained in the Westchester ores, and though it contained no insoluble corundum at all. In fact, Dr. Chatard* says of it that "the sample contained in all probability no corun-

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* The six analyses of Dr. Chatard referred to in this lecture were made at my request, and were from samples of commercial material. These samples were reduced to such fine powder that their identity was destroyed. With their origin unknown and their superficial characteristics obscured, Dr. Chatard, from chemical analysis alone, pronounces one sample of commercial corundum (southern) to be from a non-corundum-bearing rock and having no insoluble corundum at all. The sample of Westchester emery, which contained 10·14 of insoluble corundum, he classed as spinel.

As bearing strongly on popular beliefs as to the differences between imported and domestic emery, it is worth while to sum up the opinions of distinguished scientific men as to the identity and characters of various emeries.

Dr. Charles T. Jackson* gives analyses showing that the proportions of alumina and iron in Chester, Mass., emery agree closely with those of Naxos emery, and states that practical trial in armories and machine shops proved the Chester emery fully equal to the Naxos. Dr. J. Lawrence Smith† states that he considers "the Chester mineral as true an emery as that of Naxos." Dr. J. P. Kimball‡ states that the analyses of Westchester emery identify it "as a mixture of corundum with magnetite analogous to the emery of Chester." Dr. Smith|| confirms Dr. Chatard's recent identification of Westchester emery with spinel by pronouncing all emery spinel. In commenting on the discussion of Professors Jackson and Shepard, as to whether emery was a granular variety of corundum or a separate species, Dr. Smith says: "the question as to the mineralogical position of emery can be easily settled without resorting to any new mineral species. It is simply a massive iron spinel (hercynite) with the anomaly of having a hardness equal to corundum."

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* *Am. Jour. Sci. and Arts.* 2, xxxix, 90.
† *Am. Jour. Sci. and Arts.* 2, xlii, 89.
‡ *Am. Chemist*, date unknown; republished in *The Emery Grinder.* April, 1874.
|| *Am. Jour. Sci. and Arts.* 2, xlii. 83.

dum at all, being only an ordinary silicate." It was so much of a silicate that it contained 44·64 per cent. of silica, while the largest percentage in any sample of emery analyzed by Drs. Smith and Chatard was only 9·63 per cent.

Having shown that the chemical proportions of emery and corundum bear no direct ratio to price or effective hardness, we have now to consider whether there is a direct relation between effective hardness and abrasive value. In his article on "Mineralogy" in the *Encyclopædia Britannica*, Prof. M. F. Heddle distinguishes two forms of hardness. He explains the established scale of hardness which culminates in the diamond, and shows how the file test is applied. But he then goes on to show that minerals may appear soft under the file test while they scratch other minerals on which the file has no effect. This he says is because the particles are hard but loosely aggregated. Dr. Smith, also, dwells upon this point. He says that his glass and agate test for abrasive effect does not furnish the mineralogical hardness,* "two minerals possessing the same hardness but differing in structure, one being friable, and the other resisting, will be found very different in their abrasive effects." The inference which Dr. Smith draws is against the friable and in favor of the resisting material. This inference is perfectly correct so far as it relates to the exact method by which Dr. Smith secured his result, or in so far as it may relate to practical processes which reproduce Dr. Smith's conditions. It is utterly inaccurate and misleading so far as it refers to the larger proportion of modern processes in which abrasives are used. I am inclined to think that Dr. Smith's test for effective hardness by use of glass and agate is responsible for the almost hopeless confusion which exists to-day regarding the requisites of a good abrasive. The general inference is that hardness is the prime requisite.

Practical operations in emery mining prove that this inference is a mistaken one. It is no uncommon thing to find the rock overlying an emery vein harder than the

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* *Amer. Jour. Sci. and Arts.* **2**, x, 363.

emery. That is to say, it is more resisting to the action of a drill, dulling the tool more rapidly and demanding more time to drill an equal distance. If the class of hardness shown by this rock were the right kind, it ought to make a good abrasive, but actual trial shows that it does not do so. Its hardness is probably due to its compact aggregation.

In Dr. Smith's famous test, which has been copied by all his followers, separate grains of emery, not bound to each other or to anything else, but rolling and moving freely, are rubbed between two pieces of glass or between glass and agate. If these grains are loosely aggregated or if they are of bad shape (for instance, flat and thin, with splintery edges), they will, being unsupported, crush down rapidly between the hard opposing surfaces, while fragments of diamond or sapphire would stand up larger and do more work.

The practical question, however, is, how many modern processes reproduce Dr. Smith's test conditions. Emery is principally used on wood and leather wheels, in solid wheels and in the form of emery cloth or paper. It is also used on the lapidary's wheel. If the latter is a lead wheel the emery becomes embedded in the lead, the lead being selected because it is soft enough to allow of the emery grains sinking into it, and so being supported and backed up. When used on the wood and leather wheel emery is attached to the leather band by a coat of the strongest, toughest glue. The emery is forced into the hot, plastic glue, which fills all interstices in the grain, adapts itself to every peculiarity of shape, and then hardens into a perfectly fitted bed or backing which supports and braces the grain. When used in solid wheels emery is still more thoroughly braced and backed up, for it is first mixed with a base and then united with such base by gums, glues or cements, aided by the processes of slow drying, baking heat, vitrifaction, tamping and hydraulic pressure. When emery is used to make emery cloth and paper it is also bedded in and backed up by glue.

In not one of these cases do the emery grains have any free motion of their own. They do not change place in

relation to each other, and are not worn-out by the friction of emery with emery. They do not break down and crush to pieces, for they are not only backed but surrounded by their protecting matrix, and so cannot flatten, spread and squeeze apart as does a free, unsupported grain of which only a small part comes in contact with the opposing surfaces. Still another vital condition of Dr. Smith's test is lacking in the cases of the lead wheel, the leather-covered wheel, and the emery cloth and paper. In these cases the emery is not rubbed between two unyielding surfaces, such as glass and agate, but between one yielding and one unyielding. Before the grain can crush, the leather, generally chosen for its sponginess and compressibility, will yield—the lead will allow the grain to sink deeper in its surface, the cloth and paper will do the same. These latter, so thin as to possess little compressibility, are often backed up by the human hand, which affords the same cushion as does the spongy walrus or sea-horse.

Of these differences in the conditions of use the ordinary buyer takes no more note than does the professional expert. He applies, in a rough way, the same sort of test as does the expert—a test which only shows what the emery will do under conditions entirely different from those in which it will be used. He placed some of the emery on a smooth, solid piece of metal, and presses it as hard as he can, and with a sliding motion, with another piece of metal. If the grains are loosely aggregated or badly shaped they crush to pieces and the emery is condemned. Another test is to place the emery in the palm of the hand and rub it together with the thumb or finger. Here the emery is used as an abrasive agent to destroy itself. The thin edges and sharp corners are ground off and the emery is condemned as soft and dirty.

It appears, therefore, that looseness of aggregation, or friability, and also the shape of grain, may be of importance. It is in the larger grains that friability shows most markedly, and it is quite probable that this friability differs very greatly in grains of different size. If emery is a varied mechanical mixture minute subdivision may lessen the

variety of materials in each grain and so alter the standard of cohesion and aggregation. Where the grain, in crushing down, sets free particles of pure sapphire, it seems clear that these will not crush to pieces as the more heterogeneous grain did. Even if a coarse grain were proved too friable for some special work it would not follow that finer emery from the same ore was also too friable. It is an important fact that the proportion of coarse grain in use has greatly diminished and that few processes really demand a very coarse and a very resisting grain. The manufacturers of plows and of fire-proof safes, and the workers in granite are those who seem most inclined to coarse emery. The coarser it is the more resistant must be the grain, for the more it projects beyond its glue bed the more easily will it break off or crush down. It is an interesting fact that emery which is pronounced too soft for such use may be adapted to it by special processes. Whatever machine or process may be used to accomplish this, the principle of its operation is to abrade the emery by friction against itself till sharp points, brittle corners and loosely adhering particles are removed.

Concerning the comparative values of round-grained emery and that of other shapes much difference of opinion exists. The rounded or cubical grain of large size will certainly be most resistant, and, in all processes which reproduce the conditions of Dr. Smith's test, will probably be most valuable; but it does not seem evident that any advantage will attach to such shapes when they are embedded in a solid mass. A rounded or cubical grain of the finest grained, hardest and most compact ore would probably be the best for granite workers, because their processes are such as to crush a friable grain. It is this fact which has led to the growth of a new industry in the manufacture of artificial abrasives. Chilled shot and crushed steel have already won a position among stone workers and will probably have lasting and increasing sale.*

* The makers of crushed steel report that in 1890, their first business year, they sold 230,000 pounds, which sale increased in 1892 to 460,000 pounds. I have not been able to learn the annual product of chilled shot.

A chilled shot and a grain of Westchester emery, loosely aggregated and bristling with points, afford extreme contrasts. Our facts lead to the belief that loose aggregation is not a serious defect, provided, as Dr. Heddle shows, that the particles are hard enough. The inference from his statement is that abrasive effect is proportioned to the hardness of the particles. But Dr. Heddle's file test, like the glass and agate test of Dr. Smith, lacks the principal condition in the modern use of abrasives. That condition is high speed. Penetration is effected by velocity, and abrasion is effected by the points of one substance penetrating the substance of another. A board is harder than a candle, yet it is said that a candle can be shot through a board. Glass is harder than lead, yet a bullet of lead will make a clean hole through a window. It seems possible that a like rule may hold good as to abrasives, and that mineral grains may, if used at the right velocity, penetrate substances harder than themselves and prove satisfactory agents of abrasion.

On still another important point does Dr. Smith's test fail to meet the requirements of practical use. It takes no note of the pressure required. If a grain of crushed steel or a diamond gem be embedded in the face of a solid emery wheel these two articles would abrade through the use of whatever projecting points they might present. As the points wear off flat faces would appear, destitute of cutting power, and no further abrasion would take place until pressure enough had been applied to crush the grains of diamond and steel and manufacture new points for them. The harder and more resistant the grains were the greater would be the pressure needed to effect this. The criterion which demands the extreme of hardness, fineness, purity, compactness and resistance in abrading minerals, is one which calls on the manufacturer for a wasteful expenditure of power, which forces on the laborer undue physical strain, which prevents his attainment of manual skill, and which exposes him to unnecessary danger. This criterion has made durability the prime requisite in abrading materials and tools—a durability which the buyer demands without

reference to the cost of his product, or to the welfare and safety of his men.

Resistance of material calls for resistance of worker, and that abrading material is best which does equal work in equal time with the least possible power and pressure. Such adaptation to its work is not likely to be found in any mineral of extreme purity or oneness of composition, whose texture is dense, whose grain is fine, whose cohesion is great. It is more likely to be found in a mineral of such friability and such varied composition as causes it to break up into changing and irregular forms under moderate pressure.

While I consider the facts thus far stated unquestionable and the inferences from them correct, I have to avow regarding emery and other abrasives, what I avowed as to emery wheels some four years ago, before the members of this Institute, namely, that there are few exact data to demonstrate my inferences. The greater the consumption of abrasives and the more varied their use, the greater is the divergence of opinions—the more hopeless the confusion—the deeper the distrust as to any scientific basis in the grinding industry. The men who employ licensed firemen to run a steam boiler, and still further protect themselves by the periodical test of their boilers, give no thought to the latent explosibility of solid emery wheels in charge of common laborers. The railroad, which sends in to the founder its own chemical formula for car brasses, pays no heed to the inherent safety of a vulcanized emery wheel or the inherent danger of a vitrified one. The manufacturer who insists on having the candle-power of his electric light guaranteed, and the horse-power of his turbine or engine measured by a dynamometer, buys the lowest-priced emery wheel he can find, but never discovers the cost of that wheel's product.

This degradation of the grinding industry is due in part to that criterion of hardness in abrasive material which has made weight and strength the criterion of the human grinder. It is due in part to the fact that grinding problems are so obscure and difficult to the skilled mechanic that he remits them unsolved to the unlearned workman. This

degradation of the grinding industry goes back to early times. In the Royal Museum at Berlin is a painting by Gerard Ter Borch, of Deventer, probably executed about 1650, which is marked by all that detail which generally characterizes painting of the Holland school. This picture represents "The Grinder's Family." The work-room is a tumble-down, wretched shed, attached to the dwelling-house. Only one member of the family is at work, unless that operation can be called work in which the mother is engaged. She seems to be searching in the hair of her young daughter for something that ought not to be there. The grown son, with almost a simpleton's face, and with tattered garments, leans idly against a post. The old father has a wide shelf, just level with the top of the grindstone, and lies upon it at full length upon his stomach, while he presses a scythe upon the grindstone. The other scythes lie out of reach on the floor. The mandril of the stone revolves in an uncovered groove in a beam, and a notch in that beam holds a wooden wedge to keep the mandril in its place. Everything indicates that activity is at a big discount—art at a low ebb and wages lower still.

It is unfair, you will say, to steal this quarter-century old example from a pastoral country like Holland. Why not go to a manufacturing country in modern times? Why not visit Sheffield, for instance? I did visit Sheffield in 1892. I asked a master cutler to show me the latest thing in grinding. He said there was no late thing. I asked him about abrasives and he said each individual grinder supplied his own, buying a few pennysworth of emery at the nearest chemist's and having it chalked up against him just as he had his beer chalked up at the tavern. He said the grinders could generally be found at work when they had no money to spend, always providing there wasn't a football match on hand. He told me to visit Rodgers' and see what they did and then he would take me outside the town to mills hundreds of years old and that I would find the tools, the processes, the conditions identical. The factory building he called "a wheel," and the vaulted dungeons, whose windows had all their glass shattered to let in the

light which the splash and slop of the wet stone obscured, he called "troughs." A strap (belt), a stone, a razor and a grinder were what constituted the grinding industry. I ignorantly spoke of the grinders as "men," but he said it was a common Sheffield saying, "he's not a man; he's only a grinder." I did go to the main establishment of Rodgers and then to a "wheel" in a valley some miles out of the city. The "wheel" was a long, dull building of cut stone. The newer part was about 100 or 150 years old, while one wing was much older—too old for the date of its founding to be remembered. The grinder was a man over sixty, and he assured me that his father and his father's father had also ground razors there. As I talked with him two younger men examined a pile of apparently worn-out grindstones, which they said were bought second-hand, when too small for other use, and, selecting one of the quality desired, split it in two pieces because it was too thick. From this dilapidated building, from these scant tools and crude processes, were evolved by grinders not thought worthy to be called men, those blades which have made the name of Rodgers famous. Inherited skill and restriction to one narrow branch of work take the place of modern improvements. As I remember this initiation into the art of Sheffield, I smile at the London merchant who wrote to America that he could get a big order for Japan if I could supply a complete plant for razor grinding.

In our own freer and more versatile country the tyranny of the trades-union has not gone so far as to insist that only the sons and grandsons of razor grinders shall learn to grind razors. Instead of old processes, perpetuated unchanged for hundreds of years, we have all the newest wrinkles. Automatic grinding machines, almost human in their complication, and which render brains almost unnecessary to the workman; and others which look beautifully on paper, and either go to the waste pile or swell the maker's account of "returned goods." We have the newest wrinkles, but no rules—the most ingenious devices, but no accepted standards—the most varied opinions, but no authorities.

While grinding processes are complicated and solid emery wheels high-class tools, and while economical grinding demands conditions based on the careful study of educated mechanics, no one establishment uses enough to enlist the interest of the educated man. Abrasives are committed to the lowest class of labor, and reports as to results drift through circuitous channels to the buyer, whose next purchase is based on the latest and most distorted report. The name of "Wellington" is so potent that often the grinder will use no other brand of emery, though he will take any and all kinds of material without discovering any difference, provided they are poured out of a "Wellington" keg and have a color not found in the original material.

Throughout the apparent discussiveness of this lecture I have carried on a sustained argument, but that argument has been so lengthy and so involved as to demand a summary of conclusions.

It seems clear to me that current opinions about abrasives have been based too much on cabinet specimens and laboratory experiments, and too little on the average products of the mine and on the conditions of modern work. It seems demonstrated that chemical analysis does not gauge accurately the abrasive capacity of any mineral—that the hardness of such material does not bear a definite relation to its purity (meaning thereby a high percentage of alumina), and equally clear that mere hardness is not the prime requisite. It seems clear that abrasive capacity depends largely on some unexplained peculiarity of structure. It seems evident that speed, time and pressure are factors too little considered in connection with the problem of safe and economical grinding. It seems settled that external appearance is a poor guide to grinding capacity; that colors, shape of grain and attractability by the magnet are not trustworthy indications. It seems clear that commercial abrasives vary in quality, and that their acceptance or condemnation depends on prejudices and notions rather than on ascertained facts as to cost of product.

Some of the causes which lead to variable and contradictory results with abrasives are those common to shop prac-

tice, but which produce far greater effects with the emery wheel than with the lathe or planer. The effective work of an emery wheel is based on its speed of a mile a minute. The correct speed is less likely to be maintained, because the pressure against the wheel is heavier and more variable than that in a lathe. The lathe tool presses with a sharp point only against the revolving work, and is so set that, after the first cut, the pressure scarcely changes.

The grinder, however, forces his work against the wheel with greatly varying strength, and sometimes adds to direct pressure a heavy leverage. I have often seen wheels slowed down till they almost stopped. Pulleys of too small diameters are used, and belts which are too narrow. Slip of belt and diminution of speed are potent factors in the problem.

Another equally potent one is discontinuity of contact. A wheel may run a mile a minute and yet be so out of round or mounted on such a light machine or shaky floor that vibration and chatter interfere with continuous contact. Instead of a mile long file passing over the work in a minute, it is sometimes only an eighth or a quarter mile file. I have examined wheels whose continuous stream of sparks suggested continuous contact, and found that only two or three inches of the surface had come in contact with the metal. The custom of imputing all variability of result to defect in the wheel and the overlooking of variability in the metal operated on is another cause of contradictory result. A class of wheels which had long suited a plow manufacturer was at last repeatedly condemned and the wheel declared worthless. After a very long interval it appeared that the plows had been changed from one homogeneous thickness to three sheets of varying temper. A class of wheels was condemned which had long suited for car brasses, and only after long delay was it made known that the first metal was yellow brass and the last phosphor-bronze. I have lately discovered by use of an improved testing machine that the quality of the test bars of cast iron is more variable than the quality of tanite wheels.

What, then, is needed, to clear up this confusion?

It seems to me that the thing most needed is a practical testing machine, which shall take the place of the laboratory test made popular by Dr. J. Lawrence Smith. Such a machine should be run by an independent engine to secure uniform speed. Pulleys and belts should be so proportioned that no slip shall occur. Floor and machine should be so solid as to do away with vibration. Test bars should be employed of the most uniform quality. And then a series of experiments should be carried out so as to establish definite standards. It should be ascertained what is the least pressure per square inch at which a cubic inch of test metal can be ground off in the least time with the least consumption of wheel material. In other words, the final economy of the process should be demonstrated, taking into strict account the consumption of wheel material, the amount of metal ground, the time occupied, the speed employed, the horse-power expended and the pressure exerted. Thus will gradually arise a fixed standard as to what constitutes a good emery wheel, and the buyer will demand an article of known and certified productive effect whose cost of product is also known. Thus will arise on the grinder's side a demand for those wheels and those abrasives which entail the least bodily fatigue. Thus will arise a public opinion which shall hold to strict account those reckless buyers who put wheels of known dangerous quality in the hands of their employés. For this machine should not only be used to ascertain the economic value of abrasives, but also to demonstrate the relative safety of solid emery wheels.

In closing this lecture, I desire to point out that it is not so much a statement of what is known about abrasives as a confession of how little is known. This confession imputes no special ignorance to the user, but pleads the great obscurity of the problem. I believe the difference between the poorest and the best of the abrasives in common use is so moderate that great expertness is required to discover it.

My object will be accomplished if, by pointing out the fallacies which attach to old-time tests and superficial indi-

cations, the way is cleared for a more scientific method of ascertaining abrasive quality—a more business-like way of getting at the economic result—and a more humane consideration of the laborer's danger and fatigue.

APPLICATION OF THE METHOD OF LEAST SQUARES TO THE DEVELOPMENT OF FUNCTIONS.

BY F. GILMAN.

The usual methods of developing a function are by the binomial series and by the theorems of Maclaurin and Taylor. In general practice, however, only a limited number of terms of the development can be calculated, and for such cases these theorems do not give the best values obtainable for the coëfficients.

Let us take, for example, the function

$$\frac{1}{\sqrt{1+x}}$$

The binomial theorem gives

$$\frac{1}{\sqrt{1+x}} = 1 - \tfrac{1}{2}x + \tfrac{3}{8}x^2 - \tfrac{5}{16}x^3 + \qquad (1)$$

We will now assume

$$\frac{1}{\sqrt{1+x}} = 1 + a\,x + b\,x^2 + c\,x^3$$

and treating

$$\frac{1}{\sqrt{1+x}}$$

as an observed quantity, we will determine the values of the constants a, b and c from the condition that the sum of the squares of the residual errors shall be a minimum.

Supposing x to vary from 0 to 1, the following table gives the values of

$$\frac{1}{\sqrt{1+x}}$$

corresponding to different values of x:

x	$\frac{1}{\sqrt{1+x}}$
·0	1·0000
·1	·9535
·2	·9129
·3	·8771
·4	·8452
·5	·8165
·6	·7906
·7	·7670
·8	·7454
·9	·7255
1·0	·7071

Hence, for the first equation of condition, we have

$$1 + a\,(0{\cdot}1) + b\,(0{\cdot}01) + c\,(0{\cdot}001) = 0{\cdot}9535$$

or

$$a\,(0{\cdot}1) + b\,(0{\cdot}01) + c\,(0{\cdot}001) + 0{\cdot}0465 = 0$$

Hence, the ten equations of condition may be written in the following form:

a	b	c	l
+ 0·1	+ 0·01	+ 0·001	+ 0·0465
·2	·04	·008	·0871
·3	·09	·027	·1229
·4	·16	·064	·1548
·5	·25	·125	·1835
·6	·36	·216	·2094
·7	·49	·343	·2330
·8	·64	·512	·2546
·9	·81	·729	·2745
1·0	1·00	1·000	·2929

The normal equations are readily formed from these, and are as follows:

$[a\,a]$	$[a\,b]$	$[a\,c]$	$[a\,l]$
+ 3·85	+ 3·025	+ 2·5333	+ 1·24488
	+ 2·5333	+ 2·20825	+ 0·95330
		+ 1·97840	+ 0·78532

The solution of these equations give

$$a = -\,0{\cdot}486$$
$$b = +\,0{\cdot}281$$
$$c = -\,0{\cdot}088$$

Hence, we have the following expression for the development

$$\frac{1}{\sqrt{1+x}} = 1 - 0{\cdot}486\,x + 0{\cdot}281\,x^2 - 0{\cdot}088\,x^3 \qquad (2)$$

The following table shows a comparison of the results of this development with that given by the binomial series having the same number of terms:

x	$\frac{1}{\sqrt{1+x}}$	$\frac{1}{\sqrt{1+x}}$ *by equation* (1)	$\frac{1}{\sqrt{1+x}}$ *by equation* (2)
·0	1·0000	1·0000	1·0000
·1	·9535	·9534	·9541
·2	·9129	·9125	·9133
·3	·8771	·8753	·8771
·4	·8452	·8400	·8449
·5	·8165	·8047	·8162
·6	·7906	·7675	·7906
·7	·7670	·7265	·7673
·8	·7454	·6800	·7460
·9	·7255	·6259	·7261
1·0	·7071	·5625	·7070

It is readily seen by comparing the third and fourth columns of this table with the second (the second representing the true value of the function) that the binomial development is very inferior in accuracy to the development given by equation (2), and which may be called the least square development. For some very small values of x, as 0·1, the results of the least square development are not quite as accurate as those of the binomial development; but even this small difference might be made to disappear by a proper system of weighting the condition equations.

Some, however, may object to the conclusiveness of the preceding table, on the ground that it does not give a fair comparison, since it is restricted to those values of the function which were used in forming the condition equations, and that the least square development might not be expected to give nearly as correct results for intermediate values of the function.

In order to anticipate this objection, I give the following

table of results, calculated for values of x intermediate to those given in the preceding table :

x	$\frac{1}{\sqrt{1+x}}$	$\frac{1}{\sqrt{1+x}}$ *by equation* (1)	$\frac{1}{\sqrt{1+x}}$ *by equation* (2)
0·05	0·9759	0·9759	0·9764
·15	·9325	·9324	·9331
·25	·8944	·8936	·8947
·35	·8607	·8575	·8605
·45	·8305	·8225	·8302
·55	·8032	·7864	·8031
·65	·7785	·7476	·7787
·75	·7559	·7041	·7564
·85	·7352	·6540	·7359
·95	·7161	·5955	·7164

It appears, from the above table, that the accuracy of the least square development is practically the same for these intermediate values of x as it was for those values by means of which it was determined. It follows from this that the accuracy of the development would not have been materially increased by increasing the number of equations of condition.

As a further test of its accuracy we may apply it to the determination of the definite integral,

$$\int_0^1 \frac{dx}{\sqrt{1+x}}$$

the numerical value of which is known to be 0·8284.

Multiplying the least square development of

$$\frac{1}{\sqrt{1+x}}$$

by dx and integrating between the limits 0 and 1, we obtain for the numerical value of the integral 0·8287, which is in error by less than one-twenty-fifth of one per cent. The value of this integral, obtained by using the binomial series with the same number of terms, is 0·7969, which is nearly four per cent. in error.

Take next the definite integral

$$\int_0^1 \frac{dx}{\sqrt{1+x^2}} = 0·8814$$

The least square development gives:

$$\frac{1}{\sqrt{1 + x^2}} = 1 - {}^{\cdot}486\, x^2 + {}^{\cdot}281\, x^4 - {}^{\cdot}088\, x^6$$

Multiplying this development by $d\,x$ and integrating between the limits 0 and 1, we obtain for the value of the integral 0·8816, which is in error by one-fiftieth of one per cent. Using the binomial series with the same number of terms, we obtain 0·8637 for the integral, which is two per cent. in error.

Finally, let it be required to find the definite integral

$$\int_0^{10} \frac{d\,x}{\sqrt{1 + x}}$$

the value of which is known to be 4·6332.

We first integrate between the limits 0 and ·1, and find as before that the integral is 0·8287. We next integrate between the limits 1 and 10.

In order to do this we write the function in a different form, as follows:

$$\frac{1}{\sqrt{1 + x}} = \frac{1}{\sqrt{x}\,\sqrt{1 + \frac{1}{x}}}$$

$$\frac{1}{\sqrt{1 + \frac{1}{x}}} = 1 - \frac{{}^{\cdot}486}{x} + \frac{{}^{\cdot}281}{x^2} - \frac{{}^{\cdot}088}{x^3}$$

$$\frac{1}{\sqrt{1 + x}} = \frac{1}{\sqrt{x}} - \frac{{}^{\cdot}486}{x^{\frac{3}{2}}} + \frac{{}^{\cdot}281}{x^{\frac{5}{2}}} - \frac{{}^{\cdot}088}{x^{\frac{7}{2}}}$$

$$\int \frac{d\,x}{\sqrt{1 + x}} = 2\sqrt{x} + \frac{{}^{\cdot}972}{x^{\frac{1}{2}}} - \frac{{}^{\cdot}1874}{x^{\frac{3}{2}}} + \frac{{}^{\cdot}0352}{x^{\frac{5}{2}}}$$

Taking this between the limits 1 and 10, we obtain 3·8063, and adding to this 0·8287, we obtain for the integral 4·6350, which is in error by less than one-twentieth of one per cent.

The value of the integral obtained by using the binomial series with the same number of terms is 4·5552, which is nearly two per cent. in error. It is evident from the pre-

ceding examples that the expression given by least squares for the function

$$\frac{1}{\sqrt{1+x}}$$

will enable us to determine the definite integral of any function of the form

$$\frac{a\,d\,x}{\sqrt{b+c\,x^n}}$$

with an accuracy far superior to that obtained by using the binomial series for the development.

As an additional example take the more complex function

$$\frac{1}{\sqrt{1+x+x^2+x^3+x^4}}$$

in which x is supposed to vary from 0 to 1; for if x were greater than 1, the function could be transformed into another of the same kind, by putting

$$x = \frac{1}{z}$$

z being the new variable.

By the method of least squares we find exactly as in the preceding case

$$\frac{1}{\sqrt{1+x+x^2+x^3+x^4}} = 1 + a\,x + b\,x^2 + c\,x^3$$

in which

$$a = -\,0{\cdot}47189$$
$$b = -\,0{\cdot}28755$$
$$c = +\,0{\cdot}20771$$

The development of this function, according to Maclaurin's theorem, gives the following values for the coëfficients:

$$a = -\,\tfrac{1}{2}$$
$$b = -\,\tfrac{1}{8}$$
$$c = -\,\tfrac{1}{16}$$

The table below shows the comparative accuracy of the two methods of development, the numbers in the second column being the true values of the function.

$$\frac{1}{1 + x + x^2 + x^3 + x^4} = f(x)$$

x	$f(x)$	$f(x)$ *by least square development.*	$f(x)$ *by Maclaurin's development.*
0·0	1·0000	1·0000	1·0000
·1	0·9487	0·9501	0·9486
·2	·8946	0·8958	0·8945
·3	·8377	·8382	0·8370
·4	·7786	·7786	·7760
·5	·7184	·7182	·7109
·6	·6586	·6583	·6415
·7	·6005	·6001	·5673
·8	·5454	·5448	·4880
·9	·4942	·4938	·4032
1·0	·4472	·4483	·3125

ENGINEERING PRACTICE AND EDUCATION.

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[*Continued from p. 394.*]

In the infancy of any new industry questions of the proper strength of the machinery, and of adopting such arrangements as shall insure economical operation, are very likely to be neglected; the main efforts of the promoters being generally directed towards making the machines work at all; and if economy is lacking, the only result is that the prices of the products are put at such a figure as to cover the expenses and provide a good profit. Then there is a strong tendency, as long as the companies can make money as fast as they desire, without attending to matters of economy, to disregard them; and if they make any attempts to increase their income, it is rather by an increase of the plant than by introducing more economical working into

what they already have. Hence it is that in the early stages of an industry, there is usually less engineering and less scientific work done than later, for scientific work is precisely what is needed to produce economy. But after the industry has been carried on for a long time by a number of people, and competition has become rife, then those who are at the head of it find themselves forced to consider questions that affect the economical working of their industry, for on the proper solution of these questions depends success or failure. It follows, therefore, that in an industrial country like our own, there is more and more demand for scientific work, and, hence, more and more demand for engineering work. I might cite a great many cases to illustrate this matter, but one of the most marked, perhaps, is that of making illuminating gas, where it has been the fact until very recently that so much money could be made anyway, that the gas manufacturers did not care to take pains to avoid waste, and very little, if any, effort was made to economize, and hardly any attempt to operate the works on sound engineering principles.

But I am digressing from my subject. Coming back then to the locomotive, let us see how the remarks I have been making apply to that. In introducing the locomotive into American practice, it became at once evident that the rigidity with which locomotives were being built in Europe was not suited for travel on roads such as we could afford to build at the time, nor for those containing as sharp, curves as it was, and still is, frequently desirable to make. Hence, to the credit of American genius be it said that our railroad men at once proceeded to introduce the modifications necessary to render the locomotive a more flexible machine, which would stay on the track, even if the latter were uneven, and if the curves were sharp and which should be so easily accessible in all its parts and so simple in construction that it could be easily repaired. Moreover, the modifications introduced by American inventive genius, were good features, even after the country developed so that we could have better permanent way, and some of these points are of such decided advantage that we find more and

more tendency to imitate them, on the part of our neighbors across the ocean, in their most modern constructions.

Now, these efforts might be said to have been attempts to make the machine work at all, and there was too much tendency to determine the question of strength of the parts by what was and is sometimes called practical experience, *i. e.*, by waiting till something broke before pronouncing it too weak, and then making it larger, *i. e.*, putting in more iron in subsequent constructions.

To illustrate the fallacy of such a course by a very extreme case, I may say that, in the early days of locomotive practice, parallel rods were sometimes made of circular section, and that as soon as the speeds became at all considerable, such rods were almost sure to break. Now, suppose the course outlined above were followed and a larger rod of circular section substituted in subsequent construc tions. Any one at all familiar with the scientific principles at the foundation of the theory of the way in which a beam resists a transverse load, could easily predict the result, which is that the new one would be practically no stronger than the old one, while weighing more; for, as soon as the speed of the locomotive is at all considerable, the transverse load, due to the action of centrifugal force on the parallel rod, forms by far the greater part of the load that it has to sustain, and by the course adopted this load would have been increased in the same proportion as the power of resistance of the rod. A little figuring in such cases would save a great deal of costly experience, and often a number of accidents. Of course, railroad men know better now than to use round parallel rods, but there is not care enough taken yet in calculating the strength and stiff. ness of all the different parts of locomotives.

Turning, now, from questions that involve the strength of materials to those that involve economy, we find that fuel, both wood and coal, has been so easily and so cheaply obtained heretofore that railroad men paid little or no attention to this matter; and while I do not believe that the locomotive is as wasteful of fuel as is frequently imagined, nevertheless, hardly any really serious efforts

were formerly made to ascertain and develop means for reducing the coal consumption, such as have been made constantly in the case of large stationary and marine engines, and it is a fact that the man who would run a stationary or a marine engine of like power, with as large a coal consumption as is used in the case of the locomotive, would be deemed a very wasteful man and unfit for his business. Of course, the peculiar duties of a locomotive, and the special conditions under which it has to work, may not, and probably will not, enable us to realize as great economy as we do in the other cases, but it is certain that a little earnest, scientifically conducted work would enable us to realize more economy than we do, and how much more we cannot predict until more attempts have been made in a thoroughly scientific manner.

Even where tests have been made, we find a laxity allowed in them which would not be tolerated in making tests of a marine or stationary engine. As an example, I have frequently looked over the results of some locomotive test, hoping to gain some information from it, and when I came to examine the way in which the test was made, found that the conditions were such as would render it entirely untrustworthy if it had been made on a stationary or a marine engine, and I cannot see how the fact that it is a locomotive makes the test where there is so much looseness any more trustworthy. To cite the various improper things that are done in this regard would take too much time, and I will only mention one which has been done altogether too often, viz.: applying the steam engine indicator to one cylinder alone, and guessing that the performance of the other is like unto it. The chances of reaching the truth are not much, if any, greater than if the whole estimate had been made by guessing, and this latter course would have saved work. But we are coming to the time when our railroads can no longer afford to disregard questions of economy of fuel; and these matters are, slowly it is true, but surely, coming into prominence.

One evidence of the state of affairs to which I refer is the remarkable indifference that existed only a few years

ago in regard to the introduction of the compound locomotive. It had at that time already been introduced into Europe for several years, and although it had not really gone very far beyond the experimental stage, it had, nevertheless, been so far developed that it had been experimentally proved without question that a decided saving of coal could be effected by its use. Nevertheless, I listened to discussions among railroad men held at that time where very little interest was shown in furthering its introduction here, and where I heard grave doubts expressed as to whether it would be wise to introduce it into America, and when they attempted to give their reasons for these doubts, they would raise all sorts of objections as to very minor points which it would be very easy to adjust to our needs by the exercise of a very little American ingenuity and adaptability. The compound locomotive, however, came to America, and came to stay; and so prompt have Americans been to adopt it, that we now manufacture a great many in this country.

Of course, those that we have made are decidedly American and not copies of European styles, and most all of our large locomotive works now build more or less of them; and naturally we have a number of different styles, inasmuch as they have been planned and worked out by different men.

But now, if we are going to imagine that there is gain in the simple fact of compounding without regard to how it is to be done, what proportions of cylinders should be employed and what other arrangements should be used, we shall not realize the economy that we might, and we may even fail to realize any; since it will be perfectly possible for a well-proportioned and well-made single locomotive to be more economical than a badly made compound one. If, on the other hand, the introduction of the compound locomotive is to mark the beginning of an era when the same criteria of accuracy and reliability shall be applied to determine the value of a locomotive test as are applied in the case of stationary and marine engines, where we demand and perform more or less experimental work with scientific accuracy; and if the same sort of work

shall be demanded and performed in the case of the locomotive, then the benefits conferred by the introduction of the compound locomotive will not be confined to the cases where it is used, but will also react in bringing into being a more economical class of single locomotives, while it will also cause us to adopt in the design of compounds such features as will be conducive to the greatest economy of coal.

I suppose that after having said so much about compound locomotives, I ought to say a few words by way of explaining what is a compound locomotive, and what is the reason why we are justified in expecting any greater economy with it than with a single locomotive.

In the single locomotive there is one steam cylinder on each side near the forward end, and the steam from the boiler enters each of these cylinders, and causes the respective pistons to move. Before the motion of the piston in either cylinder is completed, however, the steam supply is cut off, and the piston is caused to complete its stroke by the expansive force of the steam. Then during the return stroke the steam on this side of the piston escapes into the exhaust, while that which enters on the other side of the piston is pushing the piston the other way and doing the work.

Thus, in the single engine, the steam enters the cylinder, is cut off at a certain fraction of the stroke, expands, and then escapes directly into the air; and this series of actions is carried on in each cylinder independently of the other, there being really two separate engines connected to the same shaft with the cranks at right angles to each other.

Now, in the compound locomotive, the steam, when it comes from the boiler, enters one cylinder called the high-pressure cylinder, but, when it has expanded in this cylinder, it does not escape into the air, but into another and larger cylinder, where it expands again, and acts upon another piston by its expansive force, and then, from this cylinder, it escapes into the air.

Again, there are a variety of such arrangements that can be made; thus, we may have one high-pressure and one low-

pressure cylinder on each side of the locomotive, *i. e.*, one compound engine on each side, making a pair of compound engines. This arrangement is called a four-cylinder compound. Another arrangement is made by having only two cylinders for the whole locomotive, the high-pressure cylinder on one side and the low-pressure (a larger) cylinder on the other side. A third arrangement is by having one compound engine on each side of the locomotive, the high pressure being inside of the low pressure, the latter being annular and having an annular piston. Then still another method, which is English, is to have two high-pressure cylinders, one on each side of the locomotive and one large low-pressure cylinder underneath, in the middle.

Now, these different arrangements are made by different builders, and each one claims advantages for his own. As to which is best, when the proportions are correctly adjusted, only careful and accurate experiment can determine. As to the reason why we should expect any gain by compounding, it is merely because the difference of temperature of the walls of the cylinder, when the steam enters and leaves it, is less, and hence cylinder condensation should be less, in a good compound than in a single engine, since the expansion is all completed in one cylinder in the latter, whereas it only completes its expansion in two cylinders in the former.

Besides this, there are a great many questions of interest and of importance to be made the subject of careful investigation, in connection with railroads and locomotives. I cannot pretend to give a list, but will mention a very few, as follows: The law of variation of train resistance, or the force necessary to draw the train at different speeds; the air-brakes, about which a number of questions should be investigated; heating, ventilating and lighting cars, etc. Thus, heating of passenger cars by steam from the locomotive has come to stay, and has become so much of an accomplished fact, that it has been adopted on a large number of roads, and will have to be on all; but there are a great many different possible ways of accomplishing it just as there are many ways of heating a building, and

there has hardly any progress been made as yet in regard to ventilating passenger cars.

But I think I have said enough to give you an idea of what a multiplicity of engineering questions arise, and what an amount of engineering work and opportunity for investigation there is about a railroad.

Bridges.—The greater number of our largest bridges are built to form a portion of a railroad, for, in this case, heavier loads are to be supported than when they form a part of a highway. The Brooklyn suspension bridge, which possesses the second longest span in the world, is no exception, for it carries a cable railroad. Their construction is sometimes undertaken as that of public works, as, for instance, by the city or town, and at other times it is carried on by private enterprise. The city, the railroad company, or other corporation, may impose on its own engineer the task of producing the entire plans, both the foundations and the superstructure; or it may delegate the making of these plans to another engineer or to some bridge-building firm; or, on the other hand, in the case of the latter, it may be only the superstructure which is entrusted to the firm to construct, while the foundations are kept as a separate undertaking to be built by the road itself beforehand. When an engineer has to plan a large bridge, it often happens that the foundation is by far the most difficult part of the work. Thus, at the places where the foundation is to be established there may be clay or hard sand, and, on the other hand, there may be quicksand or mud. He may have to build the foundations on piles, if it is not too large a bridge, or he may have to excavate, sometimes to a great depth, before he reaches something that is suitable for a foundation.

Then, again, he may have to establish his foundation under water, and here he may be called upon to perform a great deal of excavation. If it is to be far under water, he may have to resort to pneumatic caissons; and now by the use of machinery we are finding the means of establishing foundations under water at a depth too great to permit of the use of pneumatic caissons. In any of these cases there is a large amount of engineering involved in planning the

work, and also in executing it. A thorough examination of the ground has to be made, including the taking of borings to ascertain how deep the excavation will have to be before something is found which is suitable for a foundation, and the nature of that something. Then the plans have to be made and all necessary calculations to determine what should be constructed, and how it should be built.

Next comes the building of the foundations, and this may involve a large amount of engineering work, especially if pneumatic caissons have to be used, and if part of the work is to be built under water, as the whole erection will involve the introduction of a large amount of machinery, including the use of compressed air, cranes which have to be operated by some kind of power, hoists, etc., and the greatest care will have to be exercised in sinking and locating the caissons, and in preventing them from getting out of place while the excavations are in progress, and in preventing accidents. Then, when the excavation is made, the whole must be adjusted and all must be properly filled up with concrete, and then the masonry can be built above. Of course, this sort of work with difficult foundations is not the every-day work of the engineer in general, but all varieties of foundations are met with where the piers cannot be built directly on the ground, and where we must either build on piles or must have recourse to coffer-dams, and thus be able to excavate the earth until we reach a suitable foundation, or where some sort of crib has to be built, which shall confine a certain amount of loose and flowing sand, and thus render it suitable to build upon. Moreover, the matter of securing a good foundation is an all-important prerequisite for building a bridge that is to stand. Otherwise our bridges would share the fate of those of the old Romans.

Then comes the designing of the bridge, in such a way that it shall have sufficient strength in all its parts to resist the stresses coming on those parts. Moreover, in this work care must be taken to figure every detail, and nothing must be disregarded, for if one of the minor details be neglected in the calculation, this neglect may lead to disaster. It is

very common now, however, for a railroad company to build, or have built under its own direction, the masonry foundations for all the bridges on its road, to *erect* all of them itself, but to have them built, and sometimes also designed, by some bridge-building firm. Now, when the designer, whether he belong to the railroad or to the bridge works has made the design, and has worked out the stresses in all parts of the structure, including all the details, pins, rivets, fastenings, hangers, anchors, etc., and has also made the detail drawings of the bridge, these drawings, or rather the blue prints, can be sent into the shop, and the construction of the bridge can begin.

Making the design, the calculations and the drawings, of course, requires engineering work, and especially an application of the strength of materials, to see that every detail is of the proper strength and stiffness. But I propose to call your attention especially to what engineering work has to be done by the bridge builder in fitting up his shop to do this kind of work properly; and this will be made most evident by a consideration of the engineering problems which one who carries on a bridge works has to solve, and the engineering work he has to execute.

Of course, the method of carrying on the manufacture of bridges, and the amount and character of the engineering work involved, will depend upon the magnitude of the works, which may be small or large, and which may be built for the purpose of merely manufacturing the bridges from iron or steel which they buy, or which may be attached to, or form part of, an iron or steel works.

If they are very large and are connected with an iron and steel works, they may begin with the ore, and make their own pig iron, then transfer it to the Bessemer converters, or to the open hearth furnaces and make the ingot steel, or to the puddling furnaces and make wrought iron. Then the product is rolled, or squeezed, or hammered into blooms, and then these are cut into suitable lengths, and after being heated again, are rolled into angle irons, channel bars, T-irons, Z-bars, plates, etc.

By way of illustration, we will consider the following brief

outline of the method followed at Phœnixville, *i. e.*, at the Phœnix Iron and Steel Company's Works. At one time they used to make their own pig iron, but now they buy it and convert it in their open hearth furnaces into steel.

After having been in the reheating furnace, the ingot goes to the first set of rolls, where it is rolled into blooms, and then to a powerful shears, where it is cut into the lengths needed for different purposes.

In connection with these rolls and shears, which are very heavy, there is some ingenious machinery for performing what may be called the handling of the ingot, *i. e.*, for placing it in the right position on the rollers which feed it into the rolls or shears, for tipping it over when it is desired to do so, etc.

Of course, provision is made in this portion of the works for quick and convenient handling of the heavy ingots, etc., by means of trucks and cranes.

Then from the blooming mill the blooms are placed on trucks, which are drawn by a small locomotive to the rolling mill, where they are heated again, and then rolled into the desired shapes, angles, channel bars, **I**-beams, etc., and these are then cut off to the proper lengths by saws. In cases where it can be done, the sawing is performed while the steel is hot; but in a number of cases it has to be done when the steel is cold. Then, after leaving the rolls, the beams, channels, angles, etc., are straightened in machines with which the shop is fitted for this purpose. There are also certain machines specially designed to cut the ends in various shapes, such as are needed in fitting different pieces together in the manufacture of a bridge.

The rolling mill is, of course, fitted with a complete system of trolleys and other devices for handling the material, for delivering it to the rolls, for receiving it when it has passed through, transferring it to the next place through which it has to pass, etc. When the beams, channels, angles, etc., come from the rolling mill they are ready for the market, or to be used in the manufacture of bridges.

Then, there is the bridge shop, where all the different pieces that are to compose the separate girders and the

other parts of the bridge are assembled, and the necessary punching, drilling and riveting is performed.

Of course, this shop must be large enough to admit of whole girders being put together, and also easily handled and worked upon. Here, therefore, there are provided ample floor space, large and powerful travelling cranes to handle very heavy material, and punching machines, drilling machines and riveting machines in very considerable number. Of the latter, some are hydraulic riveting machines, conveniently located for the work they have to perform, but fixed in position; while others are portable riveters, operated by compressed air. Then there are many other machines which I will not stop to enumerate. Then, in the yard is a travelling crane, used to load the separate girders and the other parts of the bridges on to cars.

The works are very extensive, and there are numerous other shops used for various special purposes, but I shall not speak of them, as I am not attempting to give you all the details of the Phœnix Works, but only to illustrate to you what kind of operations have to be carried out and what kind of engineering problems present themselves for solution outside of the design of the bridge.

Now, in such works everything that can be done to save labor in handling, or in any other way, is, of course, so much gain. Hence the absolute necessity for a complete system of trolleys, etc. Then again, since holes for rivets and other purposes have to be located, and other features marked by template, whenever some more expeditious method has not been devised, you will find that the various bridge works endeavor to devise some machine to perform as much of the punching or drilling as possible without using a template. This becomes of special importance in the case of the long lines of rivet holes that have to be made in the plates and angle irons which are used to form the flanges and webs of plate girders; so, at these bridge works we find a machine devised for this special purpose.

Without going further into detail, it is plain, after a bridge is designed and the drawings are all made, and it is ready to be constructed, that in connection with the works a large

amount of engineering work must be performed. Of course, the planning and building of the shops in such a way as to be well adapted to their intended purpose, the selection and arrangement, the devising of suitable machinery, some of which (and sometimes considerable) is special machinery, the arrangement of the power plant, and the entire arrangement of the cranes, trolleys, etc., for handling the material, and for loading the finished structures on to the cars to be carried to their destination, all involves a large amount of engineering; and this does not cease with the establishment of the works, for the same kind of engineering questions are constantly arising—questions of mechanism, questions of strength of materials, questions of steam, etc.

At the New Jersey Iron and Steel Company's works electric cranes are used, and some of the machinery in the bridge shop is driven by electric motors. At Edgemoor, is another bridge works where the entire arrangement has been recently laid out with especial reference to convenience and ease of handling, and also to the use of special machinery, and I will outline briefly some of the methods followed in these works in order to show the sort of planning that was performed.

The material is received by rail in the yard, and is taken off the cars, and placed on little trucks running on narrow gauge tracks, on which it is rolled along and taken into the shop.

There are numerous lines of rails, parallel to one another and leading to different parts of the shop. These rails extend the whole length of the shop in one direction, and hence, the motion of any piece in the lengthwise direction is accomplished by means of these trucks. When, however, the material is to be moved in a transverse direction, it is carried by chain falls attached to trolleys moving on rails on the ceiling laid in a direction at right angles to the rails on the floor. This system of rails on the floor running in one direction and rails on the ceiling running in a direction at right angles to them is adopted throughout the greater part of the shop; but when the larger

pieces have already been formed, they are handled by means of a series of jib-cranes actuated by hydraulic power, in which the jib can be made to rise, and lift the piece, and also to turn around, while the chain falls can be moved lengthwise along the jib.

This method of handling the material is peculiarly adapted to such work, because the pieces that have to be handled are mostly long and narrow.

Next, as to the special machinery in use. The following is the method of making the eye bars from a straight bar. The straight, flat bars of proper size are taken to some small furnaces where the ends are heated; then, when hot, the ends are put flatwise into an upsetting machine actuated by hydraulic pressure, where they are upset, and formed into the proper shape for the head by being squeezed between suitably formed dies. This having been done, the bar is at once carried to a hydraulic punching machine, where the hole for the eye is punched usually before the end of the bar has had time to lose its heat. When the eyes have been punched it is straightened if necessary, and then taken to the boring machine, where there are two tools, by means of which both eyes are bored at once.

Then the eye bars are taken on the trucks to the annealing furnace. Here a number of them are put into the furnace together and annealed.

There is also at these works a multiple punch with a specially designed feeding mechanism for the purpose of punching the holes in the plates, angles, etc., of a plate girder, or of any other construction of this character, as in the case of a bridge column. The remainder of the machinery I shall not refer to.

Of course, there have to be powerful pressure pumps to provide pressure for all the hydraulic machines, of which there are many and powerful ones, such as the upsetting machine, the straightening machine, the punches for the eye bars, the hydraulic jib-cranes, etc.

It is plain that the planning and putting up of such a shop, with proper regard to economy of labor and economy in all parts, involve a large amount of engineering, and

of the kind that would usually be called mechanical rather than civil engineering, although the building of bridges has commonly been associated with the latter.

Certain styles and sizes of bridges can be made at the works and shipped to the places where they are to be erected; but when they become very large, they outgrow the capabilities of the bridge works, and a great part of the construction, if not all of it, has to be performed on the ground. In these cases a great deal of engineering work of very varied character is often involved.

Perhaps it will be well to illustrate the character of the work that may have to be done by referring to examples of one or two modern bridges, first making a few general remarks:

(1) While some very large wooden bridges have been built, and while there are still in existence in the United States a great many more bridges built of timber than there ought to be, nevertheless, they are rapidly disappearing, and bridges of any considerable size and importance are no longer made of timber.

(2) Masonry bridges are limited in span.

Hence, the modern bridges of long spans are built of iron or steel; and the necessity is constantly arising to cross greater and greater widths; and, every little while, one is built with a span greater than any that has preceded it. Thus, the famous Britannia tubular bridge, built by Robert Stephenson, in 1850, had two central spans of 459 feet each, and shore spans of 230 feet each, and was thought at the time to be a triumph of engineering. It carried the railroad across the river in rectangular wrought-iron tubes.

To us, to-day, it and others built like it look old-fashioned and cumbrous. Since then many girder bridges have been built in various parts of the world.

By way of arched iron bridges we have quite a number, but the most noteworthy are the two hat were built over the Douro River, at Oporto, Portugal, and the Garabit viaduct, over the Truyère River, in France, all of them having been built by Mr. Eiffel, and having spans of 525, 571 and 541 feet, respectively.

Of suspension bridges I will only mention the Brooklyn bridge, with a span of 1,595 feet, designed by Roebling, and opened in 1883.

At the time this bridge was built, this was the longest span in the world, and it has not yet been outdone by any other suspension bridge; but now we have the Forth bridge with a span, of 1,700 feet; how long it will be before a bridge is built with a longer span is difficult to say.

The central span of the Brooklyn bridge is 1,595 feet in length between the two towers. These towers are built on solid rock, 78 and 45 feet, respectively, below high water, and the tops of the towers are 277 feet above high water. The clear headway at the center is 135 feet. There are four suspension cables, 15½ inches diameter, each made of 5,282 galvanized steel wires, side by side, without any twist. The width of the bridge is 85 feet. At the center, and 12 feet higher than the rest of the bridge, is a footway 15½ feet wide; then the passages for teams are on the outside and the cable railroad between the footway and each of the passages for teams.

When it is necessary to span a considerable width, and to leave a considerable clear height underneath the bridge, and when it is either not possible, or not allowable, to build false work underneath, we have to build the bridge out from the supports. Whereas several bridges have been built out from the supports by dint of special contrivances, the two kinds that would seem to be best adapted to it are suspension bridges and cantilever bridges. A cantilever is the name given to a bracket fixed at one end and free at the other, the loads being placed either at the free end of the bracket or anywhere along it. Now, in order to render a bracket or cantilever able to bear a load, it must be fastened in some way at the fixed end so that it will not tip over, since the other end is free. Also, the cantilever, if loaded at the end, needs to possess a greater resistance the nearer we approach the fixed end, hence it should have a greater depth at the fixed than at the free end. Now, the idea of a cantilever bridge is to have projecting from each of the two supports a bracket or cantilever, these two projecting brackets

approaching each other, and covering a large part of the distance to be spanned. Then a plain bridge girder is hung from, and supported by, the two free ends of the two cantilevers, and spans the remainder of the distance.

Now some provision has to be made to keep the cantilevers and their supports from tipping over. This is accomplished by having another bracket extend from each support in the opposite direction, and tying down the free ends of these brackets in some way, as by tying them down to weights of sufficient magnitude resting on the ground, or by any other means that will hold them down.

Hence, we find that cantilever bridges have a bracket, deepest at the supports, extending out each way from the support, the river bracket supporting at its free end one end of the central truss, while the end of the shore bracket is tied down in some way. In cases where it cannot be tied down, as where there are two cantilever spans in succession, of course the two brackets projecting from the middle support in opposite directions are easily balanced as far as dead load is concerned, and then sufficient stability to take care of the moving load must be given by providing a sufficiently large base for the pier or support to rest upon, the moving load bearing, of course, a small proportion to the dead load.

The cantilever bridge over the Niagara River near the Falls, was the first bridge ever erected in the United States, and in the world that deserves the name; although in one sense any continuous girder bridge might be called a cantilever bridge, and although several bridges have been cantilevers during the building, *i. e.*, they have been built out from the supports, such as the Douro bridges, or the St. Louis bridge.

This cantilever bridge over the Niagara was designed by Messrs. Schneider, Field and Hayes. It was contracted for on April 11, 1883, and opened on January 1, 1884. The river span, or distance between the piers, is 470 feet; the distance from each shore abutment to each tower is 195 feet, each tower panel being 25 feet, and each river arm 175 feet, while the central girder is 125 feet long, and the total length, exclusive of the approaches, is 910 feet.

The largest cantilever bridge in the world, and also the one having the largest span, is the Forth bridge. This is a railroad bridge, and crosses the Firth of Forth not far from Edinburgh. The estuary at this place is very much exposed to heavy gales and rough seas, but just here is the island of Inchgarvie, situated about half way across; and this was the only place in the entire width of the stream where an intermediate support could be established. To bridge the distances from Inchgarvie to the north shore, and from Inchgarvie to the south shore, would require very long spans; thus the spans actually adopted in the Forth bridge were 1,700 feet, whereas, in 1873, a company had actually begun the erection of a suspension bridge at this same place, the spans of which were to be 1,600 feet each, but the destruction of the Tay bridge by the wind in 1879 brought about the discontinuance of the work, and the decision was made to erect a cantilever bridge. The plan was approved in 1881, the work was begun in 1883, and the bridge was opened in March, 1890. There are, as has been explained, two river spans; hence, in the bridge proper we find three supports, one on the north shore, one on Inchgarvie, and one on the south shore. Each of these supports or towers has a cantilever projecting from each of its two sides, or, if we call a tower and its two projecting cantilevers a double cantilever, we have, in the bridge proper, three double cantilevers. Then uniting these in the two main spans are the two central girders. Of course, the roadway is very far up above high water, and hence there are long approach viaducts on both the north and the south sides.

The dimensions are as follows: Total length of bridge, including the approach viaducts, 8,296 feet, or excluding them, 5,330 feet. The central tower on Inchgarvie, 260 feet long; the other two, each 145 feet. Each of the six cantilevers is 680 feet. Each central girder is 350 feet. This makes each clear span in the river about 1,700 feet.

Each of the three towers is supported on four circular granite piers, so placed that the centers of the four form the corners of a rectangle, whose width is in all three cases 120

feet, but whose length is, in the case of the tower on Inchgarvie, 270 feet, and, in the case of each of the others, 155 feet.

The greater length on Inchgarvie was necessary in order to give the middle tower sufficient stability, since it could not be tied down like the other two. On top of these piers rest the towers, each of which consists of four columns well tied together by suitable bracing. These columns approach each other, two and two as they rise, so that their centers at the top form a rectangle only 33 feet wide instead of 120, the length of the rectangle being the same as at the base. Of course, there are skewbacks between the bases of the columns and the piers.

While the materials were brought from elsewhere, practically all the work had to be performed on the ground, hence it was necessary to build and equip very large works. These were situated on the south shore, whereas smaller works had to be established on the north shore and on Inchgarvie, and easy means of communication had to be established between them, and between them and all parts of the work, for freight, for passengers, and also by means of the telephone. Moreover, the works had to be fitted with a very large amount of machinery, a great deal of which was special machinery designed for this particular work, as will be seen later.

The planning, erecting and superintending of these very large works alone involved an enormous amount of engineering of all sorts, the design and purchase of some, and the manufacture of other machinery, the erection of shop buildings suitable for their purpose, the arrangement of the machinery, the selection and arrangement of the various power plants, the establishment of a complete system of electric lighting, of a complete system of telephonic communication, of complete facilities for travel of the workmen by boat and by rail, and for the carrying of the materials to the points where they were needed, by rail or boat, as well as the establishing of all the machinery for handling the material, as cranes, etc., and of the means of running this machinery; the establishment of suitable means of receiv-

ing and distributing the materials, the steel, the fuel, the cement, the sand, etc., the plants for making and distributing compressed air, and a host of other matters, including the erection of a very considerable number of houses for such of the workmen as could not easily find quarters elsewhere. The amount of engineering work required to carry on all this properly is so great that it is difficult to form an adequate conception of its magnitude. In order to aid in the formation of this conception, I will give a few figures illustrating the enormous scale of the operations involved in this work, before I proceed to the further description of the details of the bridge and of the work.

The total amount of steel used in building the bridge proper, *i. e.*, the three double cantilevers and their two central girders, was about 51,000 tons. The total number of rivets used is uncertain, but is considerably in excess of 6,500,000.

There were used, up to November 30, 1889, 64,315 cubic yards of concrete, and 48,356 cubic yards of rubble, and 27,429 cubic yards of cut stone. The provision for carrying materials from the works on the south shore to the places where they were needed consisted of four steam launches, eight large steam barges, and a lot of barges or lighters which were towed by some of these.

To carry the workmen to and from work, and from one station to another, they provided a paddle steamer capable of carrying 450, and also used the steam barges and steam launches, and besides this they had to have a number of special trains run on the railroads.

Now we will proceed to consider a few of the details.

The entire weight, of course, is taken at the bases of the columns that compose the towers. These columns rest on skewbacks, which, in turn, rest on the piers, *i. e.*, the column at its base terminates in a flat plate, which rests on another plate, which latter is fixed to the pier. In the case of each tower, one of the four upper plates is rigidly fixed to the lower plate, but the other three are left free to slide on their respective lower plates, in response to change of temperature, or to wind pressure, etc.

At all three stations a large amount of preparatory work had to be done to render it possible to establish the works. Thus, on the south shore, where the works were very extensive, a jetty, 2,100 feet long and 50 feet wide, was built on piles; and on this jetty a number of temporary lines of rails were laid, with sufficient space between them to store a great deal of the material as it arrived. From the shore end of this jetty an incline, operated by a rope and a stationary engine, led to the underworks, and all the material went down this incline, as well as the pipes conveying hydraulic pressure. Branches from the railroad led to all parts of the works to facilitate the delivery of the material to and from the furnaces, shops, etc., where it was operated upon. Of course, there was a full quota of cranes for loading and unloading. Not far from the jetty were laid down launching ways of timber, wide enough to take, side by side, two caissons of 70 feet diameter each. The ground where the works were placed had to be first levelled off in terraces, inasmuch as a great deal of level ground was necessary for the works. Here were established a carpenter's and joiner's shop, a large drawing loft, extensive drill roads, a great deal of space out-of-doors for erecting separate parts, and a great many shops containing an enormous amount of machinery, the greater part of it having been specially designed for these works. This plant kept on growing during all the five years that the bridge was in process of construction, so that the cost of the plant was not far from $2,500,000. On Inchgarvie the rock all over the west end of the island had to be cut down to seven feet above high water, and ground had to be filled in and about 100 yards of sea wall built in order to be able to erect the necessary works there. Also, the whole space between the piers was covered with staging made of iron, its area being 10,000 square yards. The verticals for this staging had to be put in place by derrick cranes, and adjusted at the bottom by a diver, and a pin projected into the rock to hold them. Indeed. the erection of this temporary work alone is worthy to be considered as quite a notable piece of engineering.

It was on this island also that the tests were made to determine the greatest pressure of the wind likely to come against the bridge.

The work was carried on night and day, and hence the entire place had to be lighted, not only the shops, etc., but also the particular parts of the bridge where work was going on. For this purpose, three complete electric lighting plants were built and operated; the one on the south shore, however, was, of course, far the larger.

From this brief sketch it is plain that there was a large amount of engineering of varied character required in establishing the works, and in making preparations for the erection of the bridge. It was like building very extensive shops, furnaces, power plants, special machinery, and providing transportation facilities for five years, with the full knowledge that the works must be no longer operated at the end of that time, but all the machinery and appliances must be sold.

Two of the piers on Inchgarvie, and all four on the south shore, had to be founded so far below low water that they had recourse to pneumatic caissons. I will give a brief description of them, and will endeavor to word my description in such a manner as to explain what is a pneumatic caisson, and how it is operated.

The caissons used in this case were made of wrought iron. Their form on the outside was that of a cylinder surmounted by a truncated cone, the diameter of the cylindrical portion being 70 feet, while the small diameter of the conical part was 60 feet; on top of this was fastened the temporary caisson.

Seven feet above the bottom, we find an air-tight floor, strongly braced. Above this floor is put concrete in such quantity as at first to cause the caisson to float with the desired immersion, and afterwards to cause it to sink. The space below the air-tight floor is in the form of a truncated cone, 70 feet in diameter at the bottom, and 56 feet at the top, this being the working chamber, or the chamber where the excavations are made. Three shafts, each 3 feet 7 inches, connect this air chamber with the top. When the

caisson is in operation, one of these shafts serves for the ingress and egress of the workmen, and the other two for the ingress and egress of the materials.

Now, the height of the entire construction, *i. e.*, permanent caisson with temporary caisson attached on top, must be sufficient to reach above high water when the caisson is fully sunk. A little above the top of the permanent caisson are found the tops of the three shafts already mentioned, and at the tops of these shafts are airlocks, through which entrance into, or exit from, the shafts, and hence the working chamber, is effected.

Of course, the internal construction of the caisson would reveal a large amount of heavy bracing, but I shall not undertake to describe it. We thus have in a caisson, as it were, a huge diving bell, into the working chamber of which we force compressed air. This drives out the water, and the caisson, being so loaded as to descend just the right amount, and the compressed air being let on, the workmen proceed to make the excavation, and the material excavated is drawn up by a hoist through the shafts. After the excavation was completed, and the caisson had been sunk to its final resting place, the working chamber was gradually filled up with concrete, and also the shafts, and they then proceeded to fill the whole up with concrete to the level of low water, and at this level began the masonry piers.

The caissons were built at the launching ways, where they were riveted up with hydraulic riveters. When completed, they were launched at high tide and towed to the end of the jetty, where the temporary caisson was attached, and the machinery, etc., was put on, and then they were towed to position.

The granite piers were begun at 18 feet below high water, *i. e.*, at low water level, and here the diameter of each pier was 55 feet, and they were built up to 12 feet 8 inches above high water, the diameter here being 49 feet.

When the piers had reached a level of seven feet below high water, a staging was built at the height of the bedplate on which the columns of the supports were to rest. By

means of this staging, and a template of the bed plate, the holding down bolts were put in place and built in. There were forty-eight holding down bolts in each pier; they were made of a special kind of steel, and had a diameter of two and one-half inches, increased to three inches at the ends where the screw thread was cut.

As much of the work as possible was drilled with all the parts put together; there were a great many special machines, as plate-bending, multiple-drilling, edge-planing, multiple-riveting and others, and portable hydraulic riveters, all specially adapted to the special work to be done.

The work of erection was first carried on to a height of fifty feet above the tops of the masonry piers, and, after that, hydraulic lifting platforms were constructed and used in the central towers. By means of these lifting platforms, the material was raised to the level required, and then it was taken to the point where it was to be used. These platforms were lifted by means of hydraulic rams placed in the central towers. Now, when the cylinder was anchored at any one height, the extent to which the platform could be lifted was the stroke of the ram. When it had been lifted thus far, it became necessary to raise the cylinder of the ram and to anchor it higher up. An ingenious arrangement, which I will not stop to describe, was devised to attain this object. A very ingenious riveting machine and cage was devised and used in doing the enormous amount of riveting which had to be performed in place.

It is plain that the engineering work involved in designing the bridge and its foundations, and making the necessary calculations and drawings, was very decidedly less than that which had to be performed in the construction of the bridge, the latter comprising an enormous variety.

Now, this is the largest bridge in the world, *i. e.*, the one having the longest spans; but engineers are, as a rule, a progressive body of men, and they are constantly devising and erecting works of greater magnitude than any that have gone before, so that it is very doubtful how long it will remain the largest.

Of course, the amount of engineering work involved in

erecting small bridges is far less than in the case of such a bridge as the Forth, but it is all a matter of degree, and the making and erecting of any bridge of any importance requires a great deal of engineering work. Thus, in the case of a moderate sized bridge more or less elaborate works must be on the ground, to handle the material and to perform the work which has to be done there, and which may involve riveting, drilling, punching and a variety of other operations.

Indeed, now that electricity is becoming so much used for the transmission of power, it is not at all unlikely that it, too, will come into play to a considerable extent in the work of erecting bridges and of building them.

Moreover, whereas the designing and building of bridges has been usually associated with the idea of civil engineering, it is plain that a large, if not the larger, part of the work is such as is usually called mechanical engineering; or, rather, it seems to me that we are forced to the conclusion that there is no one portion of engineering that belongs exclusively to civil engineering, and no one portion that belongs exclusively to mechanical engineering, but that all belong to engineering.

Time will not allow me to take up a number of other cases of what are commonly called public works, and which involve a great deal of engineering. Thus, were I to describe to you the details of the piercing of the Mont Cenis or the St. Gothard tunnel, or our own Hudson River tunnel, which, though not completed, is a work of great merit; or were I to describe the operations connected with building canals, as, for instance, the Amsterdam Ship Canal, the Manchester Ship Canal, the Suez Canal, or even the Panama or the Nicaragua Canal, or the operations connected with the improvements of rivers, the building of ports, of docks, etc., you would find again a condition of things similar to that already explained. All these matters require a very large amount of engineering work of all kinds, and also the use of the most modern appliances in the way of machinery of all sorts, including, of course, the steam plant, etc.

[*To be continued.*]

ARMOR PROTECTION FOR HEAVY GUNS IN BATTLESHIPS.*

By Wm. C. Foley.

In a modern battleship, where a high rate of speed is required, one of the chief aims of the designer, in the disposition of the main armament, is to ensure it a maximum protection with a minimum of weight; consequently, wherever weight can be saved without detracting from the offensive and defensive power, or seaworthiness of the vessel, it is of great importance.

The system of mounting the heavy guns singly in several armored stations at a considerable distance apart, interferes with the efficiency of a good auxiliary armament; it increases and complicates the amount of gear necessary for training the guns, and for hoisting the ammunition to the guns; it also increases the weight of armor necessary for protection, as compared with the system of mounting the heavy guns in pairs in a less number of protected stations.

The design that combines great offensive power with a minimum weight of armor, and at the same time has the guns well protected, is the system of mounting the heavy guns in pairs in two armored stations placed at each end of the vessel, and working independently of each other, so that there is no fear of simultaneous disablement from an enemy's gun fire, as in this arrangement all the heavy guns can be utilized with the auxiliary armament for a broadside discharge. To carry guns of the largest calibre now made, ships must necessarily be of large dimensions and heavy displacement, and I think that the very heavy battleships that have been constructed, and are still being built, in foreign navies, are no doubt very good as gun platforms, but they have the drawback of not being such good sea vessels, and the point of seaworthiness has been partly lost sight of in

* Read at the Stated Meeting of the Section of Engineers and Naval Architects, April 24, 1894.

the attempt to form huge floating batteries. These large vessels roll very heavily in a seaway, and the weights being local, so to speak, the strains that are brought to bear on a vessel in such a condition are enormous, to withstand which she must be strengthened in such a manner that the weight of the hull is increased considerably at the cost of the armor protection. The writer believes that in the future, when we have gained more practical knowledge of the working of vessels of this class at sea, the limit of size for a battleship will not exceed 12,000 tons displacement. Thus in reducing the size of our battleships we can increase their number for the same amount of money expended.

As the guns of large calibre that have been tried in different navies have not been altogether successful for various

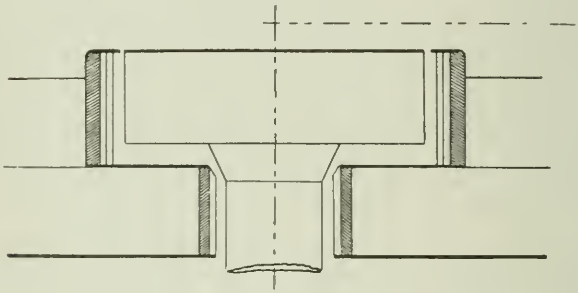


FIG. 1.

reasons, guns of a smaller calibre are now being adopted; in the British Navy, the 13·5-inch, sixty-seven ton gun being used, but the most recent ships will have 12-inch guns. In the Italian Navy they use a gun of sixty-eight tons; and a forty-five ton gun is largely used in the French Navy; and it is probable that the future guns for ships will decrease rather than increase in size, so that for illustration I have chosen a mounting suitable for 12-inch guns.

There are two systems of mountings for heavy guns, both of which are in common use; namely, "barbette mounting" and "turret mounting;" and we will now briefly review the advantages and disadvantages of each.

Barbette Mounting.—In the earlier ships built on the barbette system, the redoubt armor was only carried down

sufficiently to protect the turntable, having a thick plated bottom, the weight of which was transmitted to the hull by a circular support and by the bulkheads below. The ammunition for the guns was either hoisted up direct into the turntable, as in *Fig. 1*, in which case an armored cylinder was carried from the protective deck to the barbette floor, for protection of same; or it was hoisted up at the rear end and outside of the turntable, as in *Fig. 2*.

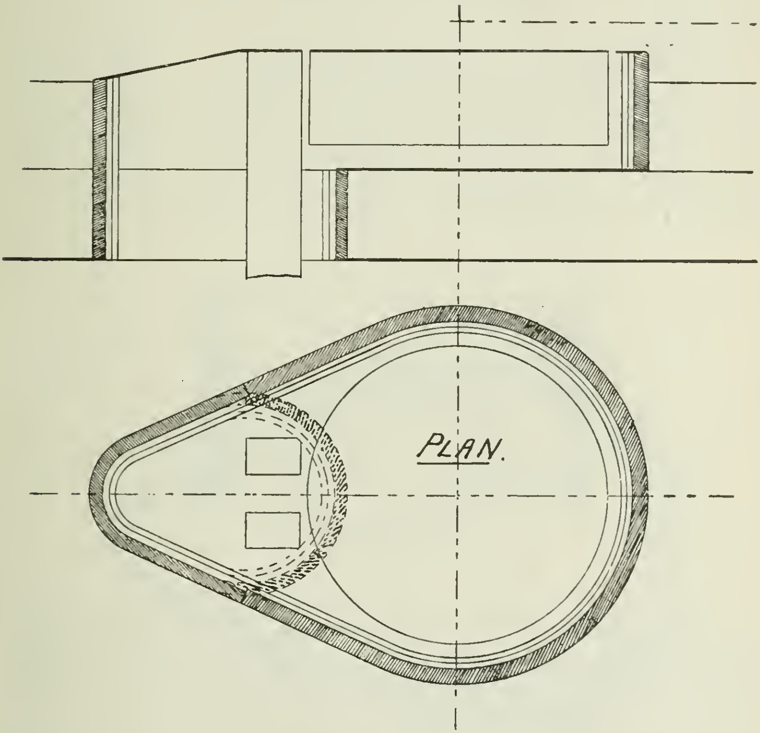


FIG. 2.

In this case the rear plates of the redoubt armor were carried down to the protective deck and an arc of armor worked round the hoists below the barbette floor. The total weight of armor, including a three-inch floor plate, was only 340 tons in *Fig. 1*; and in *Fig. 2*, which is a totally different arrangement, 430 tons. But with the development of quick-firing guns, throwing shells of high explosive power, this

system of armoring barbettes did not afford sufficient protection, as a shell bursting between decks underneath the barbette floor, would throw the turntable out of gear and thus cause the disablement of the guns; therefore, in barbettes, the armor had to be increased in depth, as shown in *Figs. 3* and *4*, an arrangement which completely protects the gun mountings. With this arrangement of armor, a shell bursting inside the ship would have to pierce the redoubt armor before any damage to the gun mounting could be sustained.

Fig. 3 represents an armored barbette, with the armor carried down to the protective deck, which, in conjunction with the side armor of the ship, completely protects the turntable and all gear. The weight of armor in this arrangement is 450 tons, or 110 tons more than in *Fig. 1*.

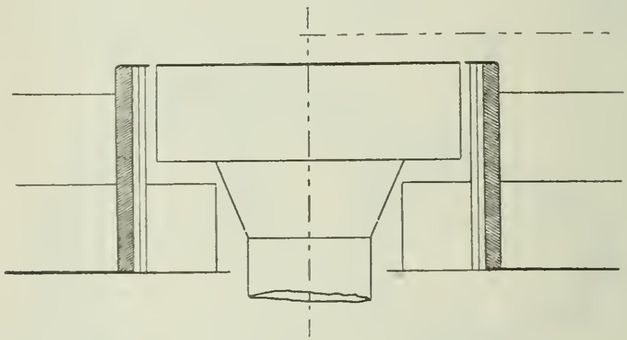


FIG. 3.

In this type of barbette, the ammunition is carried from the ammunition-passing room up through a center cylindrical tube directly to the guns. This arrangement of barbette appears to combine the highest economy in weight of armor with the maximum protection; but its disadvantages are that the carrying of the ammunition directly up into the turntable necessitates the crowding of a good deal of gear into a small space. The rammers also are placed in the turntable, being of the telescopic type; and the turning engine must be situated below the protective deck and geared up to the turning rack. In some designs a hydraulic turning engine is fitted in the turntable, and works with a short

shaft and pinion on to a rack underneath the turntable, but this adds still further to the crowding of gear in the turntable, which is not to be commended.

Fig. 4 represents a barbette with the armor carried down to the protective deck. The armor at the rear end can be decreased in thickness, as in conjunction with any diagonal

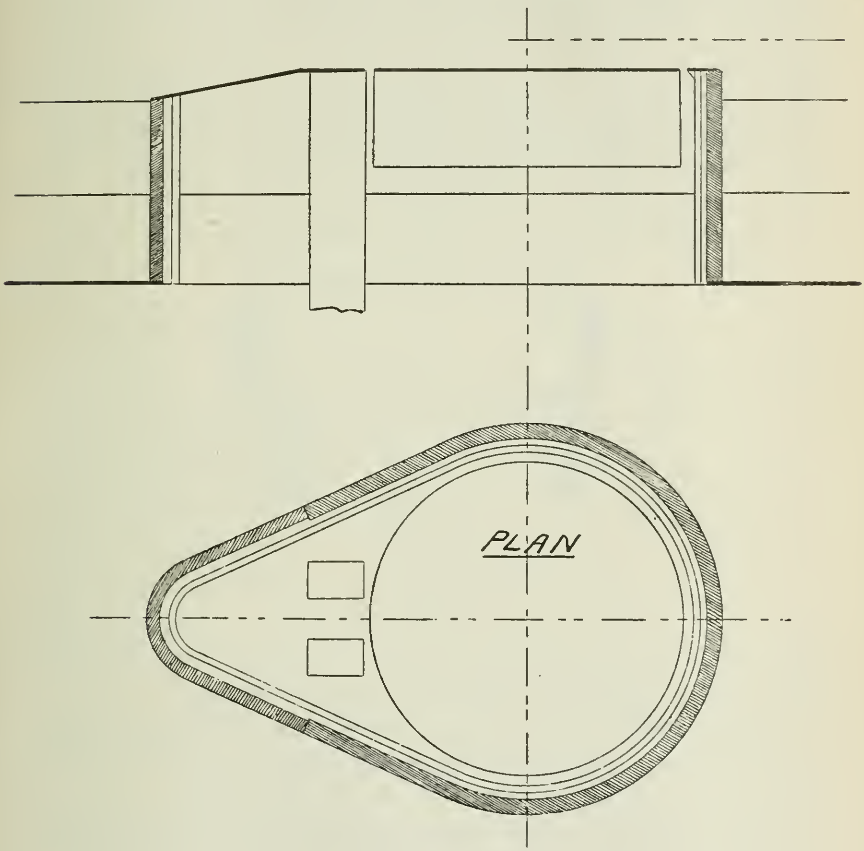


FIG. 4.

armor that may be fitted there is less likelihood of a shot striking here. The armor is shaped as shown in the plan view, *Fig. 4*. The ammunition comes up the hoists at the rear or narrow end, where the rammers are situated, and loads from the cage in the hoists into the guns. In this arrangement the guns have to be trained into the fore and

aft direction, after each discharge, to reload. This is a disadvantage, as compared with the plan shown in *Fig. 3*, in which loading can be done in any position; but a rate of discharge of one round in less than two minutes can be maintained, which is very little below that of *Fig. 3*. The turning engine, which may be either steam, hydraulic or electric, can be placed below the barbette floor, and with a short shaft and pinion wheel work on to a rack, which is placed at the extreme diameter of the turntable; this ensures smoother working and less strain on the engine.

Electric hoisting and turning engines have been fitted in some cruisers of the French Navy, and in a battleship for the Chilian Navy, and, I believe, have worked well.

The weight of armor in this barbette (*Fig. 4*), is about

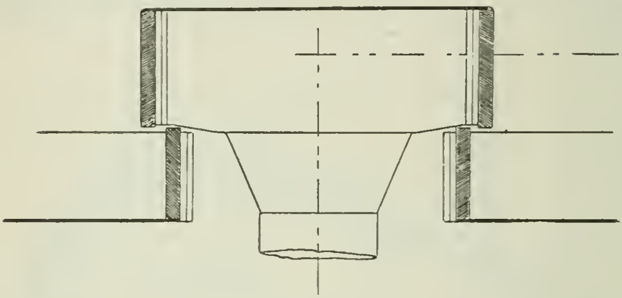


FIG. 5.

sixty-five tons more than that of *Fig. 3*, but the turntable itself is much lighter, owing to the absence of the center ammunition cylinder and gear attached to same.

Having now given a rough idea of the arrangement and working of two different types of barbettes, we will now proceed to contrast them with turret mountings.

Turret Mounting.—In the turret mounting, the protection of the heavy guns consists of fifteen-inch armor on the turret, redoubt armor also being fitted for protection of turret base and ammunition apparatus.

Fig. 5 represents a turret arrangement, the axis of the guns being seventeen feet above L.W.L., the vessel having a freeboard of eleven feet forward; weight of turret and redoubt armor being 406 tons.

Now, for sea-going battleships, a high freeboard forward is advisable, as it is possible to maintain, with such ships, a high rate of speed, and fight the guns in a seaway. In obtaining the freeboard, however, we must keep our weight as low as possible so as to have a stable ship and steady gun platform. At the same time we must not minimize our protection. Although eleven feet is enough freeboard for a coast defense vessel, or for the after end of a sea-going vessel, it is not sufficient for the forward end. A reference to the following table will show that by adopting the barbette arrangement (*Fig. 3*) instead of the turret, we get a deck more forward, giving us a freeboard of eighteen feet with

TABLE.

	Type.	Weight of Armor.			Axis of Guns above L.W.L.	Freeboard.	Thickness of Armor.		
		Turret.	Redoubt.	Total.			Tube, or Turret.	Redoubt.	Base Plate.
Fig. 1, . .	Barbette	Tube 50 Base plate	250 40	340	23′ 0″	18′ 0″	10″	15″	3″
Fig. 2, . .	Barbette	Base plate 40	390	430	23′ 0″	18′ 0″	—	15″, 12″	3″
Fig. 3, . .	Barbette	—	450	450	23′ 0″	18′ 0″	—	15″	—
Fig. 4, . .	Barbette	—	515	515	23′ 0″	18′ 0″	—	15″, 12″	—
Fig. 5, . .	Turret	250	156	406	17′ 0″	11′ 0″	15″	15″	—
Fig. 6, . .	Turret	250	315	565	24′ 6″	18′ 0″	15″	15″	—
Fig. 7, . .	Turret	140	515	655	23′ 0″	18′ 0″	15″	15″, 12″	—

an increase of only fifty tons of armor, the center of gravity of said weight being almost the same in each case.

Fig. 6 represents a turret, the arrangement and working of which are the same as for the barbette, *Fig. 3*. The axis of the guns above L.W.L. is twenty-four feet six inches, but the weight of armor necessary for protection is considerable, namely 565 tons.

But in the turret arrangement the total weight of the turntable exceeds that of the turntable in the barbette arrangement by 300 tons, and this weight it must be remembered is very high up, which is a considerable factor when

the stability is concerned. Then again the power of the turning engines must be increased to turn this extra weight.

Fig. 7 represents a turret mounting, the arrangement and working of which are the same as in the barbette, *Fig.* 4. The total weight of armor, in *Fig.* 7, is ninety tons in excess of that of *Fig.* 6, this increase being in the redoubt armor: but owing to the turntable being lower (thus reducing the depth of the turret armor), the turret armor is 110 tons less in weight than that of *Fig* 6, thus reducing the total weight of the turntable.

Other methods of working turret armor have been tried, such as having the armor on the turrets sloping. This reduces the weight of armor, but it curtails the room inside the turntable; and the armor is also difficult to roll and

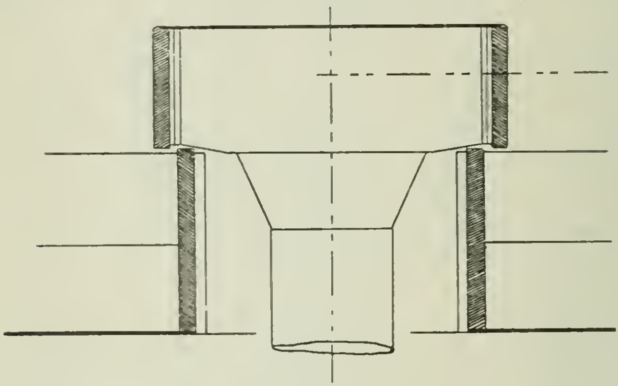


FIG. 6.

machine to the proper bevel at top and bottom. But this can be partly overcome by working the armor plates flat, thus forming a polygon in plan view. This method is adopted in the barbettes in the Italian Navy.

Backing for Armor.—The structure for holding the redoubt armor plates in position is generally formed as follows: Two thicknesses of steel plates are worked for the depth and extent of the armor, stiffened by vertical and horizontal bracket plates and angles, connected firmly to the ship's hull, and the stiffening spaced so as to allow a good disposition of armor bolts. Wood backing is then connected to the outside surface of this structure by means

of galvanized iron or steel bolts, the heads of which are sunk beneath the finished surface of the backing and covered with wooden dowels. Hempen grummets covered with red lead are placed underneath the washer of the nuts on the inside of the two steel plates, to ensure watertightness. The wood backing must be caulked and the seams payed with a waterproof composition; and before fitting the armor plates, a thick layer of red lead, or approved composition, should be applied on the outer surface. The wood backing is trimmed down from a template taken from the armor plate itself, so as to ensure an exact fit. The practice of fitting redoubt armor without wood backing is not to be commended, as there is always a certain amount of working

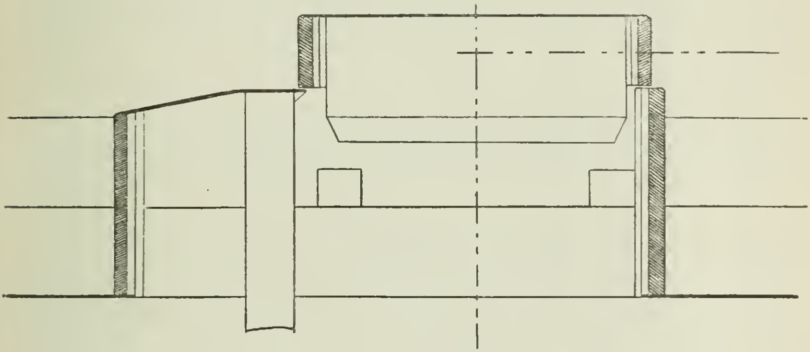


Fig. 7.

in a seaway or from the blast of the guns; and it is easier to heave up the armor bolts and maintain the watertightness of the work when wood backing is fitted. The extra weight due to fitting backing and the slightly increased diameter of armor to fit same, is more than compensated for by the efficiency of the work done.

Armor Plates.—Great care must be exercised in the fitting of the armor plates. They should be made to fit as nearly as possible metal to metal at the butts, and caulked whereever they are so fitted. Where they do not fit accurately, small pieces of metal will be driven into the spaces and then caulked flush with the face of the plate. The plates are held in place by means of bolts, standard sizes being used

for certain thicknesses of armor, the number being proportional to the outer surface of the plate. For fifteen inch armor one bolt is allowed for every four and one-half square feet of surface. Wherever the projection inward from the two thicknesses of plates must be reduced to a minimum, distance sleeves are not fitted, the bolt-head being heaved up against an india-rubber washer in a steel hexagonal cup, thus making the passage of the bolt through the plating watertight. When no distance sleeve is fitted the weight of the armor is taken on the thread in the plate itself, and not on the thread on the inner end of the bolt, as is usual where space will allow. The threads of armor bolts are similar to the thread of the breech plug of the modern gun, that is, each side of the thread has a different angle, the strain being on the steep side when the bolt is in tension, thus making it able to bear a greater strain than a thread of the ordinary screw type.

In comparing the barbette and turret arrangements we will take *Figs. 3* and *6*, as both have the same freeboard, but the axis of guns above L.W.L. is slightly less in barbette mounting. The diameter of the armor for barbette is greater, so as to admit of a turntable of suitable size for the guns, consequently there is a slight increase in the comparison of the weights of redoubt armor; but when the weight of the turret armor is taken into account, there is a saving in the total weight in the barbette arrangement of over 100 tons, which weight is at a considerable height above L.W.L. Therefore, it may be taken that in the matter of weight and horse-power of turning engine, the barbette has the advantage. It may be said that in the barbette arrangement the guns are more exposed to damage. This is quite true, but it must be remembered that the range of these guns is over ten miles, and that probably in an engagement the firing will commence at a long range, and a gun at this distance is a small object to hit. It is probable, also, that the enemy will aim at the center or highest part of the ship, and if the guns are mounted in pairs at the ends of the vessel the chance of hitting the guns is not much greater than if mounted in a turret.

In the turret arrangement the muzzle of the gun is exposed, and, if hit, is disabled, so that the protection to the guns is not much greater with a turret than with a barbette mounting. Then again, the men are as much protected in the barbette mounting as in the turret mounting, as the top of the turntable or turret is the same in each case, being protected by means of a thick nickel-steel plate, one or two thicknesses of thin plating being worked beneath the thick plate to which it is connected, by means of rivets countersunk top and bottom, to do away with rivet-heads inside the turntable, as a shot striking the thick plate would cause the rivet-heads to fly off, and be a source of danger to those working the guns. Thick steel hoods are placed on top to afford protection for sighting purposes. Another point worth noticing in the turret arrangement is this, that if the turret is struck by a heavy projectile of high velocity there is a chance of throwing the turntable out of gear. This is also a reason for keeping the roller path at the greatest diameter of turntable, as it adds to smoothness of working, and does not bring so much strain on the holding down clips.

Reference to the table shows that the comparison of barbette and turret mountings certainly favors the barbette arrangement, as far as weight is concerned, and as the turntable bases, turning gear, etc. (which after all is the most vital part of the mountings), are equally protected in both cases, the extra weight involved in protecting a small portion of the guns by means of a turret seems to be misplaced, as such extra weight might be employed in increasing the thickness of the redoubt or side armor.

The marked improvements in the manufacture of armor has been the means of a great saving in the weight of armor for a certain amount of protection. The race for supremacy between armor and guns has been carried on incessantly, and as the destructive power and penetrating energy of the projectile has increased, so also the defensive power of the armor has been increased.

From the old armor plate which we can all remember, to the compound armor plate with a hardened steel face, was a

step in the right direction, and further improvements have furnished nickel-steel and Harveyized armor plates, both of which have given good results, so that now we can use armor of half the thickness and weight formerly used and still have as great protection, and as long as we can use armor around our gun stations to resist penetration, it gives us the advantage of having our guns protected and of being able to strike a blow at any enemy.

In conclusion, the writer hopes he has placed some points before you worthy of discussion.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, May 16, 1894.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 16, 1894

MR. JOSEPH M. WILSON, President, in the chair.

Present, forty-six members and six visitors.

Additions to membership reported since last meeting, nine.

The Secretary read a letter from Mr. Thomas P. Conard, conveying his acceptance of election to the Board of Managers.

Mr. E. P. Reichhelm, of New York, read a paper describing the system and apparatus of the American Gas Furnace Company.

Mr. Louis Krumbhaar gave a description of a new apparatus designed for manifolding or producing a large number of printed copies of a document from a stenciled original made on the typewriting machine. The invention consists of an improved printing apparatus, called the "diagraph," which was exhibited and shown in practical operation by the inventor, Mr. Thomas H. Stackhouse.

Mr. Constant de Redon, of New York, exhibited a large number of specimens of aluminum soldered joints, made by the process and material used for the purpose by the Alsite Aluminum Company, of that city. He gave a practical illustration of the method of using the solder, by making a number of joints. Among the numerous exhibits presented by the company were specimens of articles of aluminum handsomely electroplated with gold and silver.

The subjects presented by Mr. Krumbhaar and Mr. de Redon were referred to the Committee on Science and the Arts for investigation.

Mr. Edward Brown described and showed the practical application of a new form of pyrometer devised by him for service in indicating temperatures up to about 2,000°.

The Secretary's report embraced an account of the salient features of the Manchester Ship Canal, which was illustrated with lantern views.

Adjourned. WM. H. WAHL, *Secretary.*

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU

T. F. TOWNSEND, WEATHER BUREAU, L. F. O. IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR NOVEMBER, 1893.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 30, 1893.

GENERAL REVIEW.

November's normal temperature and rainfall is about 40°·2 and 3·33 inches. The present month has been 1°·1 colder than the average, and the rainfall nearly half of an inch less.

The warmest period was during the first half, and the coldest occurred during the latter part of the month.

General rains prevailed on the 4th, 15th, 21st, 22d and 28th, being heavy on 4th and 28th.

Light snows occurred on various days, but Saegertown, Carlisle and Girardville were the only stations that reported any on ground at the end of the month.

No unusual phenomena was noticed during November and the month was not exceptional.

From January 1, 1893, to November 30, 1893, the deficiency in temperature was, at Philadelphia, 324°; Pittsburgh, 486°; Erie, 401, and York, 417°.

For the same period the deficiency in precipitation was, at Philadelphia, 3·34; York, 7·35; Erie, 1·99, and excess at Pittsburgh, 0·43 inch.

	Mean Temperature.	Mean Precipitation. Inches.
November, 1887,	39°·2	1·80
1888,	42°·0	3·37
1889,	41°·0	6·72
1890,	41°·5	1·49
1891,	39°·6	2·65
1892,	39°·1	4·34
1893,	39°·1	2·93

TEMPERATURE.

The mean temperature for November, 1893, was 39°·1, which is 1°·1 below the normal, and the same as the corresponding month of 1892.

The mean of the daily maximum and minimum temperatures, 48°·0 and 30·5, gives a monthly mean of 39°·2, with an average daily range of 17°·5.

Highest monthly mean, 44°·9 at Altoona.

Lowest monthly mean, 33°·5 at Wellsboro.

Highest temperature recorded during the month, 68° on the 2d at Pittsburgh.

Lowest temperature, minus 4° on the 26th at Saegertown.

Greatest local monthly range, 69° at Saegertown.

Least local monthly range, 35° at Girardville.

Greatest daily range, 43° at Hollidaysburg on the 2d.

Least daily range, 0° at Hamburg on the 4th.

BAROMETER.

The mean pressure for the month, 30·12, is about ·07 above the normal. At the United States Weather Bureau Stations, the highest observed was 30·68 at Pittsburgh and Harrisburg on the 26th, and the lowest 29·50 at Erie on the 21st.

PRECIPITATION.

The average rainfall, 2·93 inches for the month, is a deficiency of 0·40.

The largest monthly totals in inches were Coatesville, 5·69; Browers Lock, 4·81; Pottstown, 4·78; West Chester, 4·76; Phœnixville, 4·74, and Lansdale, 4·67.

The least were Somerset, 1·16; Davis Island Dam, 1·21; West Newton, 1·27; Lock No. 4, 1·35, and New Castle, 1·39.

WIND AND WEATHER.

The prevailing wind was from the West.

Average number: rainy days, 8; clear days, 8; fair days, 11; cloudy days, 11.

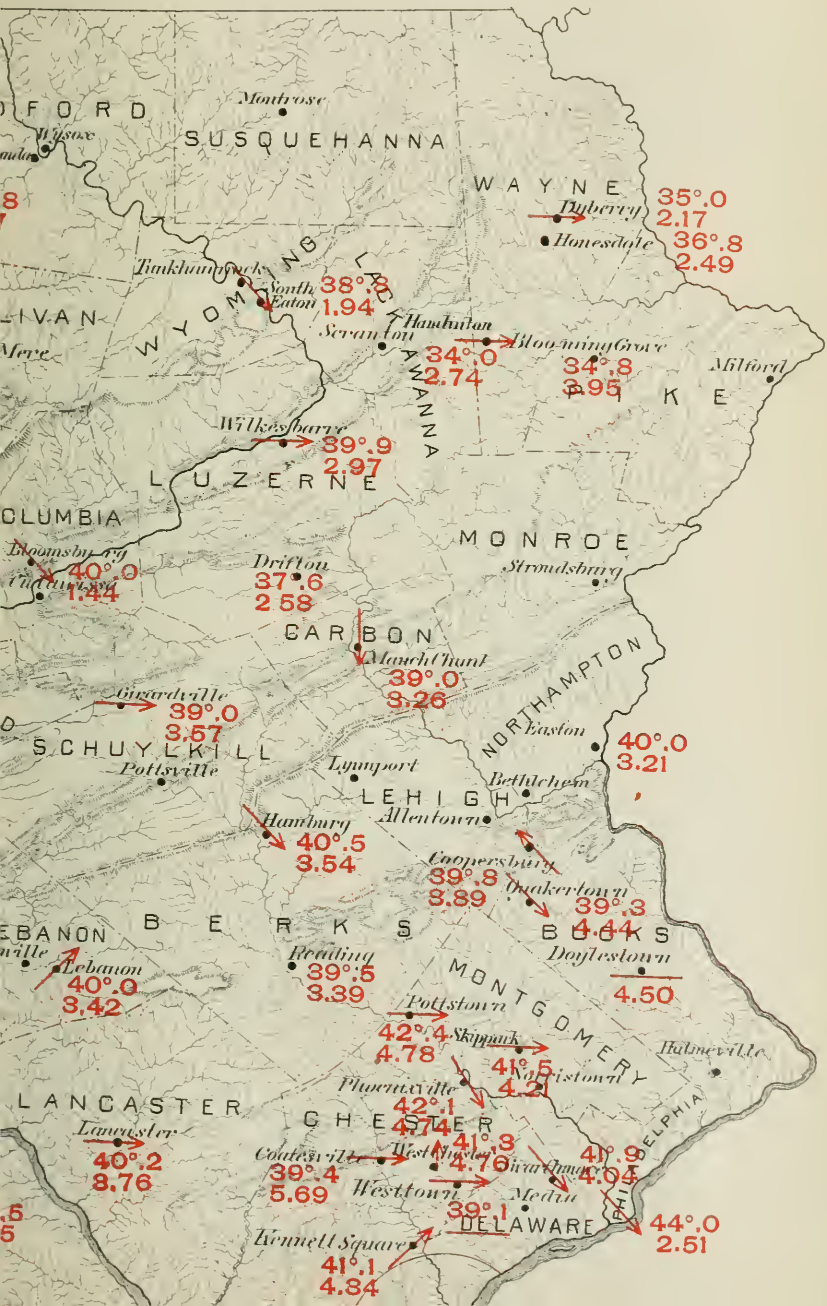
MISCELLANEOUS PHENOMENA.

Thunder.—Saegertown, 2d.

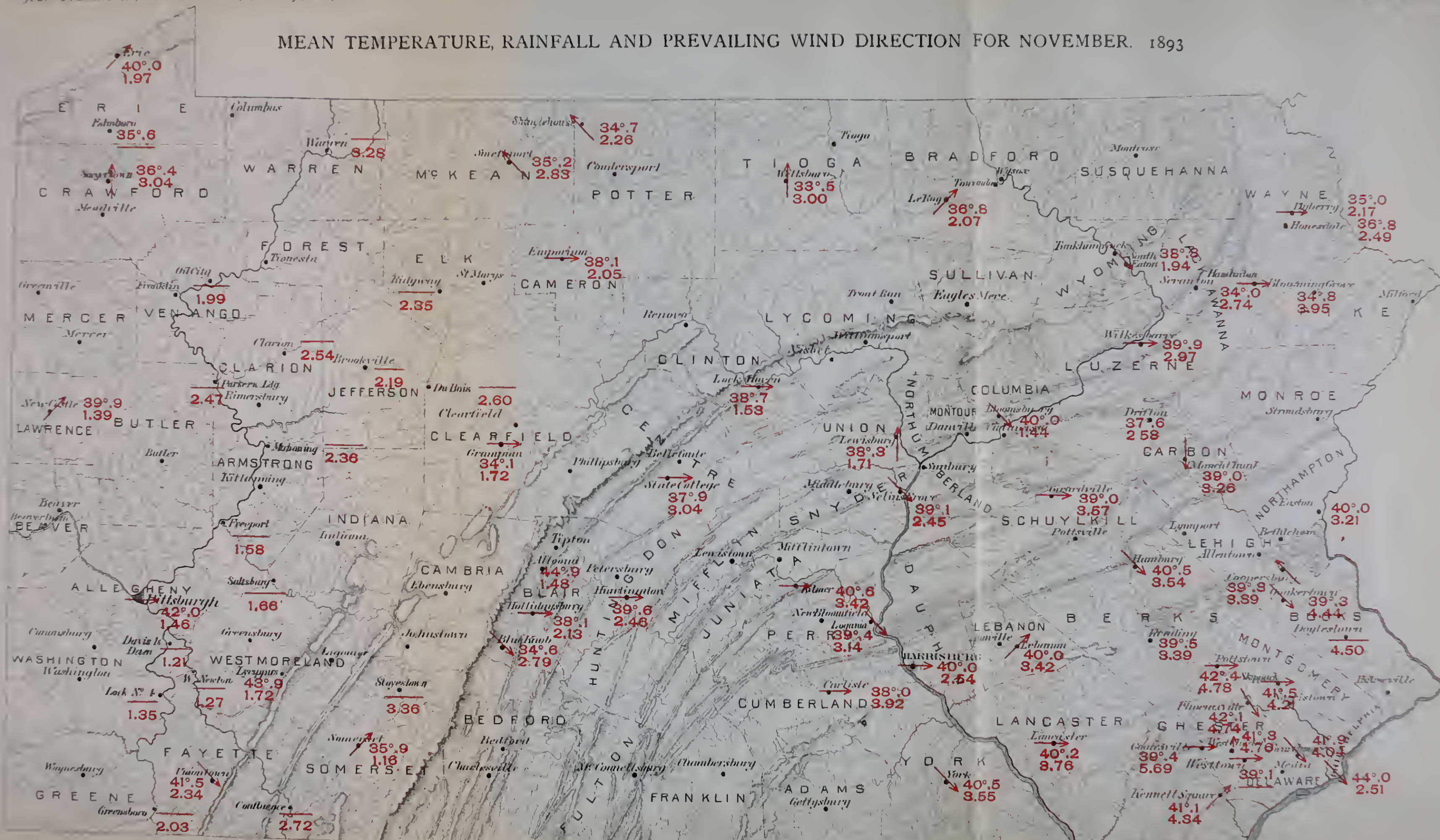
Hail.—Emporium, 22d.

Sleet.—Blue Knob, 21st, 23d, 27th, 28th; Huntingdon, 21st.

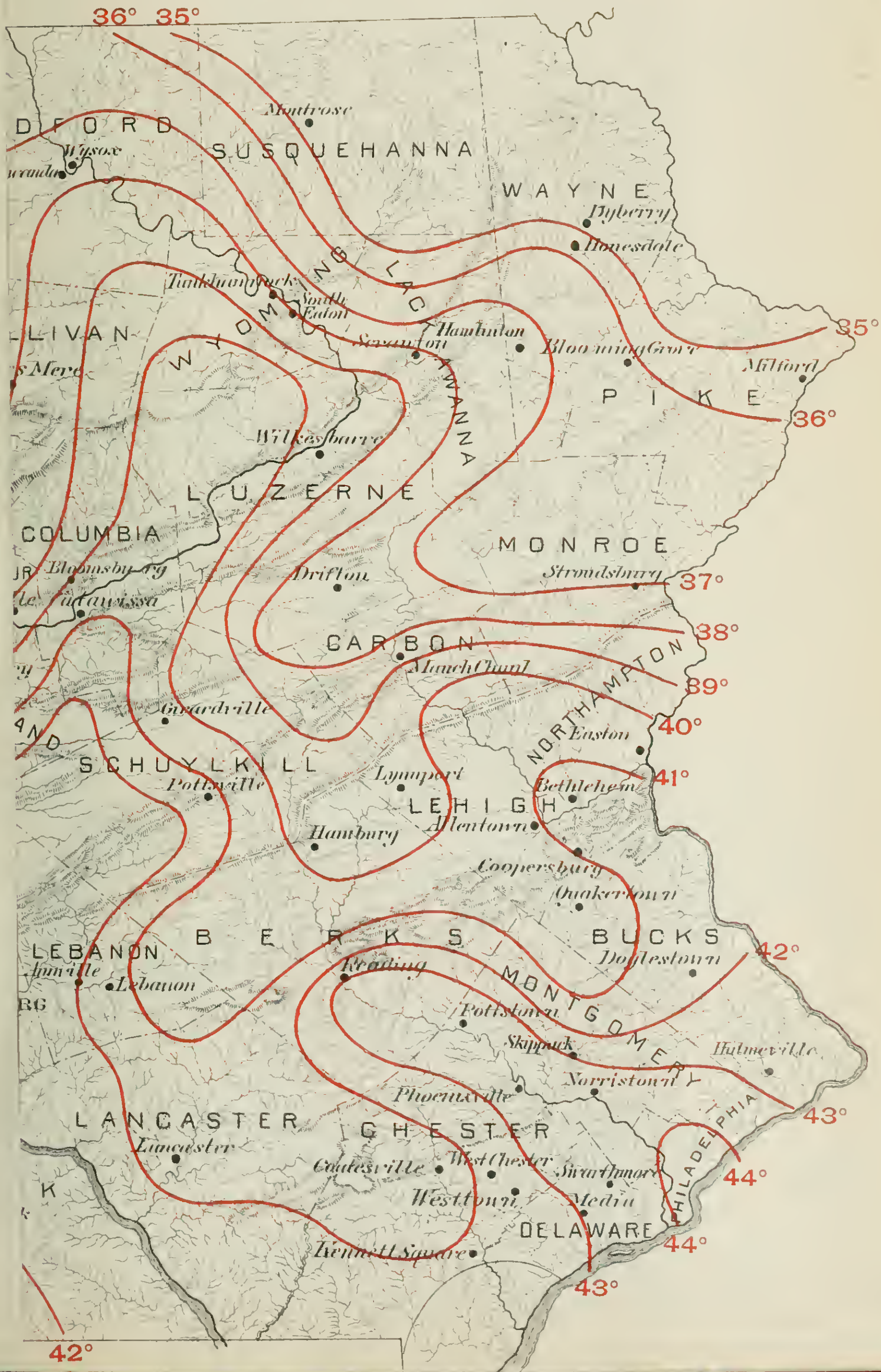
FOR NOVEMBER. 1893



MEAN TEMPERATURE, RAINFALL AND PREVAILING WIND DIRECTION FOR NOVEMBER. 1893



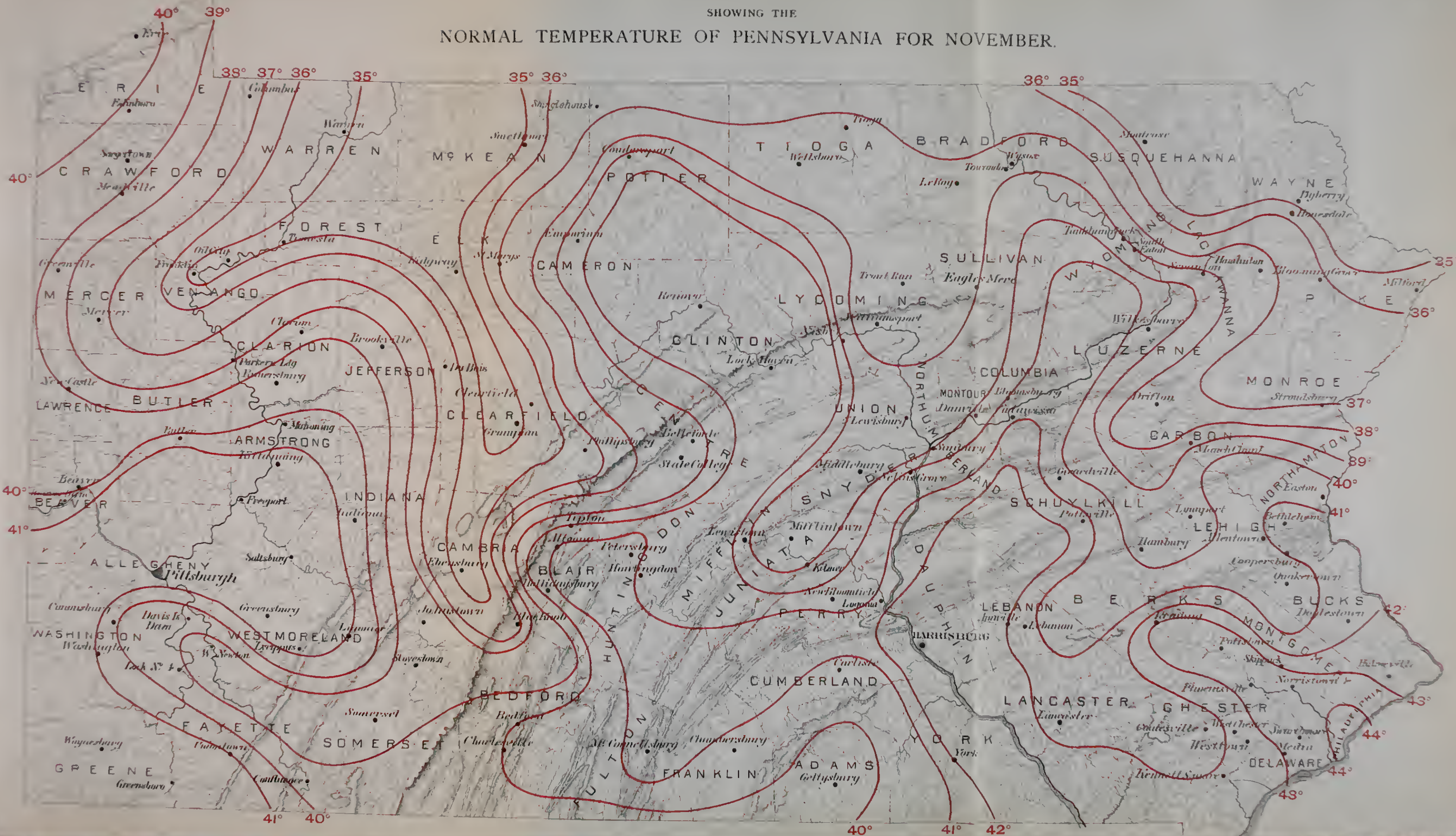
VEMBER.


36° 35°
SUSQUEHANNA
Montrose
WAYNE
Dyberry
Honesdale
WYOMING
LACKAWANNA
Tunkhannock
South Eaton
Scranton
Hamlinton
Blooming Grove
35°
Milford
PIKE
36°
Wilkesbarre
LUZERNE
COLUMBIA
Bloomsburg
Catawissa
Drifton
MONROE
Stroudsburg
37°
38°
CARBON
Mauch Chunk
NORTHAMPTON
39°
Girardville
40°
Easton
SCHUYLKILL
Pottsville
Lynnport
Bethlehem
41°
LEHIGH
Allentown
Hamburg
Coopersburg
Quakertown
LEBANON
BERKS
BUCKS
42°
Doylestown
Annville
Lebanon
Reading
MONTGOMERY
Pottstown
Skippack
Hulmeville
Norristown
Phoenixville
43°
LANCASTER
CHESTER
Lancaster
Coatesville
West Chester
Swarthmore
PHILADELPHIA
44°
Westtown
Media
DELAWARE
44°
Kennett Square
43°
42°

ISOTHERMAL LINES,

SHOWING THE

NORMAL TEMPERATURE OF PENNSYLVANIA FOR NOVEMBER.



PRECIPITATION.			NUMBE
Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rainfall.	Clear.
...	...	8	12
...	...	4	2
...	...	11	...
...	...	6	...
11·5	...	11	5
1·5	...	5	10
...	...	...	...
3·0	...	13	3
.	...	10	8
1·0	...	9	7
...	...	...	...
1·5	...	11	3
...	...	9	8
4·0	...	8	3
0·5	...	10	13
1·2	...	10	13
0·5	...	10	7
...	...	10	9
...	...	...	9
2·0	...	7	7
1·0	...	8	7
0·1	...	6	6
...	...	...	...
8·0	4·0	12	5
3·5	1·0	7	10
0·8	...	10	10
...	...	4	7
...	...	...	...
...	...	15	6
0·5	...	8	13
...	...	...	...
...	...	...	...
1·5	...	7	16
...	...	...	...
1·0	...	9	7
1·0	...	10	13
4·0	...	6	9
2·2	...	10	12
1·0	...	9	10
8·2	...	10	6
3·0	...	6	14
15·0	...	9	4
...	...	6	13
...	...	6	10
0·2	...	8	...
1·2	...	7	10
...	...	8	8
...	...	9	10
	...	6	...
6·6	.	12	6
6·8	2·0	9	6
1·5		6	0
2·2	...	7	4
3·5	...	5	3
0·5	...	4	5
...	...	...	...
7·5	...	6	4
2·0	...	7	...
6·0	...	5	1
...	...	6	...
...	...	...	...
...	...	7	9
2·0	...	8	12

sence of numerals indicates that m

Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for November, 1893.

County.	Station.	Elevation above Sea Level (feet).	Barometer Reduced to Sea Level. Mean.	Barometer Highest.	Barometer Lowest.	Temperature. Mean.	Maximum. Highest.	Maximum. Date.	Minimum. Lowest.	Minimum. Date.	Mean of Maximum.	Mean of Minimum.	Daily Range. Mean.	Daily Range. Greatest.	Date.	Least.	Date.	Relative Humidity.	Dew Point.	Precipitation. Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rainfall.	Number of Days. Clear.	Fair.	Cloudy.	Wind. Prevailing Direction. 7 A. M.	2 P. M.	9 P. M.	Observers.
Allegheny,	Pittsburgh, A,	820	30·12	30·68	29·60	42·0	68	2	16	26	50·2	33·0	17·2	31	12	6	4	74·0	33·0	1·46	...	...	8	12	10	8	W	...	W	O. D. Stewart, Weather Bureau
Berks,	Hamburg,	380	...	...	...	40·5	62	2, 6, 9	19	21	48·0	33·0	15·0	29	1	0	4	...	...	3·54	...	...	4	2	22	6	NW	...	...	William Shipe.
Berks,	Reading, A,	280	...	...	...	39·5	...	...	...	...	...	...	...	...	...	...	...	...	...	3·39	...	...	11	...	...	...	...	...	...	Franklin Yager.
Blair,	Altoona, B,	1,181	...	...	...	44·9	63	3	20	26	51·8	37·0	15·8	25	17	6	5	...	...	1·48	...	...	6	...	...	...	...	...	...	Dr. C. B. Dudley.
Blair,	Blue Knob, A,	2,500	...	...	...	34·6	58	2	0	26	40·0	29·2	10·8	26	26	2	24	...	...	2·79	11·5	...	11	5	12	13	NW	...	NW	A. H. Boyle.
Blair,	Hollidaysburg,[1]	947	...	...	...	38·1	65	2	5	26	49·0	25·2	23·8	43	2	7	4	...	...	2·13	1·5	...	5	10	12	8	W	W	W	Prof. J. A. Stewart.
Bradford,	Wysox[1],	718	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Charles Beecher.
Bradford,	Le Roy,	1,400	...	...	...	36·8	62	7	18	26	44·3	29·3	15·0	31	7	1	4	...	...	2·07	3·0	...	13	3	13	14	SW	SW	SW	G. W. T. Warburton
Bucks,	Forks of Neshaminy[1] (25 days),	304	...	...	...	41·2	...	...	...	...	...	...	...	...	...	...	...	...	...	4·06	...	...	10	8	13	4	W	W	W	J. C. Hilsman.
Bucks,	Quakertown,[1]	536	30·16	30·76	29·72	39·3	62	2	15	27	49·8	30·7	19·1	32	27	7	24	...	...	4·44	1·0	...	9	7	13	10	NE	NW	SW	J. L. Heacock.
Cambria,	Johnstown, A,	1,184	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	E. C. Lorentz.
Cameron,	Emporium, A,	1,050	30·06	30·62	29·49	38·1	63	2	18	17	46·5	29·7	16·8	37	17	3	4	90·1	32·0	2·05	1·5	...	11	3	12	15	W	...	W	T. B. Lloyd.
Carbon,	E. Mauch Chunk,	550	...	...	...	39·0	60	2, 9	15	27	47·9	30·1	17·8	32	1, 2	3	4	...	...	3·26	...	...	9	8	8	14	N	...	...	F. C. Wintermute.
Centre,	State College[1]— Agricultural Experiment Station,	1,191	30·07	30·66	29·55	37·9	59	2	13	26	46·2	26·7	19·5	27	22	6	17, 25	80·2	31·9	3·04	4·0	...	8	3	15	12	W	W	W	Prof. Wm. Frear.
Chester,	West Chester,[1]	455	30·11	30·62	29·65	41·3	60	2	21	26	49·0	34·2	14·8	27	27	5	8	72·0	32·3	4·76	0·5	...	10	13	4	13	S	NW	N	J. C. Green, D.D.S.
Chester,	Coatesville,[1]	380	...	...	...	39·4	66	2	15	27	51·5	30·1	21·4	37	2	7	28	...	...	5·69	1·2	...	10	13	9	8	W	W	W	W. T. Gordon.
Chester	Kennett Square, A,	275	...	...	...	41·1	65	2	16	27	51·3	30·9	20·4	35	11	4	8	...	...	4·34	0·5	...	10	7	10	13	SW	...	SW	B. P. Kirk.
Chester.	Phœnixville, A,	190	30·15	30·68	29·74	42·1	63	18	19	27	50·5	33·7	16·8	28	1	7	24	79·0	32·7	4·74	...	...	10	9	5	16	NW	...	NW	Knowles Croskey.
Chester,	Westtown (29 days),	350	...	...	...	39·1	62	1	18	25	47·8	30·4	17·4	36	11	5	5	...	...	...	...	...	...	9	9	11	W	W	W	Harry Alger.
Clearfield,	Grampian,*[1]	1,450	...	...	...	34·1	56	9	8	26	40·4	28·3	12·1	28	17	2	4, 28	...	...	1·72	2·0	...	7	7	11	12	W	W	W	Nathan Moore.
Clinton,	Lock Haven,[1]	560	...	...	...	38·7	65	9	17	17	48·4	28·0	20·4	32	2	5	24	...	...	1·53	1·0	...	8	7	10	13	W	W	W	Prof. J. A. Robb.
Columbia,	Bloomsburg, A— State Normal School,	500	...	...	...	40·0	65	6, 13	19	26	48·2	31·8	16·4	29	28	6	24, 25	79·3	32·8	1·44	0·1	...	6	6	12	12	NW	...	NW	Prof. J. G. Cope.
Crawford,	Meadville— Divinity Hall,[1]	1,200	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Chas. Graves.
Crawford,	Saegertown, A,	1,200	...	...	...	36·4	65	2	−4	26	47·4	25·3	22·1	36	7, 25	7	25	...	...	3·04	8·0	4·0	12	5	6	19	S	...	SW	J. G. Apple.
Cumberland,	Carlisle,[1]	480	...	...	...	38·0	61	6	15	26	47·3	30·1	17·2	30	1	6	4	...	...	3·92	3·5	1·0	7	10	12	8	W	W	W	J. E. Pague.
Dauphin,	Harrisburg, A,	361	30·15	30·68	29·76	40·0	59	9	22	27	47·0	34·0	13·0	26	2	3	4	79·0	33·0	2·54	0·8	...	10	10	9	11	W	...	W	F. Ridgway, Weather Bureau.
Delaware,	Swarthmore, A— Swarthmore College,	190	30·14	30·71	29·74	41·9	61	18	20	26, 27	48·8	35·0	13·8	29	27	4	24	86·0	35·6	4·04	...	...	4	7	17	6	NW	...	NW	Prof. Susan J. Cunningham.
Erie,	Edinboro,*[1]	1,400	...	...	...	35·6	56	2	13	26	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C. F. Sweet.
Erie,	Erie, A,	681	30·05	30·65	29·50	40·0	65	2	19	25	47·0	34·0	13·0	22	9	5	25	70·0	30·0	1·97	...	...	15	6	13	11	SW	...	SW	P. Wood, Weather Bureau,
Fayette,	Uniontown[1] (28 days),	1,000	...	...	...	41·5	65	10	15	26	49·8	33·2	16·6	29	12	5	4, 18	...	...	2·34	0·5	...	8	13	8	7	SW	NW	NW	Wm. Hunt
Franklin,	Chambersburg,[2]	618	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	G. W. Ludwig.
Fulton,	McConnellsburg,[1]	875	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	T. F. Sloan
Huntingdon,	Huntingdon, A— The Normal College,	650	...	...	...	37·6	64	2	10	26	51·1	28·2	22·9	38	2, 17	7	24	...	...	2·46	1·5	...	7	16	4	10	W		W	Prof. W. J. Swigart.
Indiana,	Indiana— State Normal School,	1,350	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Prof. S. C. Schmucker.
Juniata,	Kilmer,*[3]	475	...	...	...	40·6	60	6	19	26	...	...	...	...	...	...	...	...	...	3·42	1·0	...	9	7	10	13	W	...	...	R. J. Mickey.
Lancaster,	Lancaster, A— Franklin and Marshall College,	411	30·14	30·65	29·72	40·2	65	2	20	26	49·7	30·8	18·9	33	2	7	4	81·2	34·8	3·76	1·0	...	10	13	8	9	W	...	E	W. E. Bushong
Lawrence,	New Castle,[1]	932	...	...	...	39·9	62	2, 9	9	26	47·8	27·0	20·8	36	9, 12	8	28	...	...	1·39	4·0	...	6	9	8	13	NW	SW	W	Wm. T. Butz.
Lebanon,	Lebanon, A,	458	30·12	30·65	29·73	40·0	63	9	18	26	49·0	31·0	18·0	30	1	8	24	89·7	34·1	3·42	2·2	...	10	12	12	6	SW	...	SW	G. W. Hayes, C.E.
Lehigh,	Coopersburg,[1]	520	...	...	...	39·8	58	2, 6, 18	19	27	49·4	32·8	16·6	27	27	9	4, 5, 28	...	...	3·89	1·0	...	9	10	9	11	SE	SE	SE	Dr. M. H. Boye.
Luzerne,	Drifton (23 days), A,	1,683	30·06	...	...	37·6	63	10	12	17	48·8	26·3	22·5	41	3	4	15	85·0	35·0	2·58	8·2	...	10	6	11	6	...	...	...	J. R. Wagner.
Luzerne,	Wilkes-Barre, A,	575	...	...	...	39·9	66	1	18	27	50·4	29·4	21·0	39	1	8	24	...	...	2·97	3·0	...	6	14	3	13	W	...	W	A. W. Betterly.
McKean,	Smethport, A,	1,500	...	...	...	35·2	64	2	10	17	44·2	26·2	18·0	42	17	4	23	...	...	2·83	15·0	...	9	4	13	13	SW	...	SE	Armstrong & Brownell.
Montgomery,	Pottstown,	150	...	...	...	42·4	63	18	21	27	50·2	34·5	15·7	29	1	2	21	73·9	33·4	4·78	...	...	6	13	10	7	W	W	W	Charles Moore, D.D.S
Montgomery,	Skippack, A (20 days),	...	...	...	...	41·5	62	18	20	26	53·4	29·6	23·8	33	12	6	4	...	...	4·21	...	...	6	10	5	5	W	...	W	B. W. Dambly.
Northampton,	Easton— Lafayette College,	325	...	...	...	40·0	58	3, 9	18	26	47·3	30·4	16·9	32	27	4	4	...	...	3·21	0·2	...	8	...	...	...	...	...	...	J. W. Moore
Perry,	(Aqueduct) Logania,*[1]	367	...	...	...	39·4	59	9	19	26	...	...	...	...	...	...	...	...	...	3·14	1·2	...	7	10	8	12	NW	...	...	Richard Cal[illegible]n
Philadelphia,	U. S. Weather Bureau, A,	117	30·14	30·66	29·73	44·0	62	2	24	26	50·2	37·7	12·5	24	27	4	4	71·0	34·0	2·51	...	...	8	8	14	8	NW	...	NW	L. M. Dey, Weather Bureau.
Philadelphia,	1529 Centennial Avenue, A,	120	30·14	30·66	29·72	44·3	63	6	25	26	51·4	37·3	14·1	24	27	5	8, 13	74·2	33·7	3·81	...	...	9	10	10	10	NW	...	NW	John Comly
Pike,	Blooming Grove,*[1]	...	...	...	...	34·8	57	11	18	22, 26	...	...	...	...	...	...	...	...	...	3·95	...	...	6	...	...	...	...	...	...	John Grathwohl.
Potter,	Shingle House (28 days),	1,475	...	...	...	34·7	60	9	12	17, 21	43·4	26·0	17·4	32	6	4	25	...	...	2·26	6·6	...	12	6	6	16	SE	...	...	C. D. Voorhees, M.D.
Schuylkill,	Girardville,[1]	1,000	30·08	30·61	29·67	39·0	58	9	23	26	47·2	32·9	14·3	24	11	4	4	...	...	3·57	6·8	2·0	9	6	18	6	W	W	W	E. C. Wagner.
Snyder,	Selins Grove, A,	455	30·16	30·65	29·89	39·1	60	2	18	25	48·4	29·8	18·6	28	2	9	3	89·6	33·6	2·45	1·5	...	6	0	20	10	NW	...	NW	J. M. Boyer.
Somerset,	Somerset,[1]	2,250	...	...	...	35·9	63	2	6	26	46·3	27·6	18·7	33	2	8	25	90·4	35·0	1·16	2·2	...	7	4	6	20	SW	SW	SW	W. M. Schrock.
Tioga,	Wellsboro,*	1,327	...	...	...	33·5	60	6	18	21, 26	...	...	...	...	...	...	...	...	...	3·00	3·5	...	5	3	9	16	N	S	S	H. D. Deming
Union,	Lewisburg, A,	450	30·13	30·58	29·75	38·3	61	6	16	27	48·1	28·5	19·6	34	2	6	24	89·3	31·8	1·71	0·5	...	4	5	16	9	S	...	S	Prof. W. G. Owens.
Warren,	Columbus,	1,410	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Wm. Loveland.
Wayne,	Dyberry,[1]	1,100	...	...	...	35·0	65	2, 11	10	27	45·3	26·9	18·4	39	2	4	25	...	...	2·17	7·5	...	6	4	15	11	W	W	W	Theodore Day.
Wayne,	Honesdale,[1]	1,000	...	...	...	36·8	58	2	12	27	45·7	27·9	17·8	32	1	7	4, 25	...	...	2·49	2·0	...	7	...	...	...	...	...	...	John Torrey
Wayne,	(Salem Corners) Hamlinton[1] (23 d.),	1,600	...	...	...	34·0	56	9	18	26	40·9	28·2	12·7	21	11	3	28	...	...	2·74	6·0	...	5	1	12	10	W	W	W	T. B. Orchard, M.D.
Westmoreland,	(Immel Reservoir) Lycippus,*[1]	1,420	...	...	...	43·9	62	2, 6	24	26	...	...	...	...	...	...	...	...	...	1·72	...	...	6	...	...	...	...	...	...	Murray Forbes
Westmoreland,	Ligonier,	1,750	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	J. T. Ambrose.
Wyoming,	South Eaton, A,	660	...	...	...	38·8	62	2	20	26, 27	47·4	30·1	17·3	30	7	6	4, 25	...	...	1·94	...	...	7	9	13	8	NW	...	NW	B. M. Hall.
York,	York, A,	385	30·10	30·56	29·73	40·5	63	29	17	26	50·1	31·0	19·1	34	2	7	5	88·7	35·1	3·55	2·0	...	8	12	8	10	NW	...	NW	Mrs. L. H. Grenewald

A, Observations taken at 8 A. M. and 8 P. M. B, Observations taken at 12 Noon. * Extremes from dry thermometers. [1] Mean temperatures, 7 + 2 + 9 + 9 ÷ 4. [2] Mean of 8 + 8 ÷ 2. [3] Mean of 7 + 7 ÷ 2. Absence of numerals indicates that mean of temperature is from maximum and minimum readings.

6	7	8	9	10	11	12	13	14	15
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PRECIPITATION DURING NOVEMBER, 1893.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin.																																
ooming Grove,			.14	.60											.38			.60			.47							1.76				3.95
ewers Lock,				1.73	.38				.56				.04		.47							.56						1.07				4.81
oatesville,				1.68	.30			.68	.47				.05		.60			.01			.43	.25						1.02				5.69
Coopersburg,				1.61	.11			.01					.03		.39			.01			.38	.29						1.06				3.89
lestown,				2.00	.19			.11	.13				.05		.41						.06	.46						1.09				4.50
berry,			.15	.30											.30						.25	.10						1.07				2.17
ston,			.01		1.15								.02	.02	.43			.01				.62						.95				3.21
s of Neshaminy,			.03		1.75			.17	.17				.03	.01	.43						.13	.39						.95				4.06
rederick,				1.97	.28			.13	.12				.04		.50						.21	.33						.90				4.48
amburg,				1.60										.41							.81							.72				3.54
onesdale,			.13	.55											.27		.03	.07			.40							1.04				2.49
Kennett Square,				.79	.41			.13	.63				.09	.01	.60						.40	.37						.91				4.34
ansdale,				2.00	.25			.41	.25				.03		.40						.25	.17					.91					4.67
Mauch Chunk,			.03	.93	.13										.24			.02	.02		.03	.67						1.19				3.26
tsville,				1.70	.45								.04								.02	1.00						.98				4.19
iladelphia, a*				.40	.26				.42				.05		.43						.18	.38						.39				2.51
iladelphia, b,				.75	.38			.02	.61				.06		.49						.23	.53						.74				3.81
enixville,				2.03	.11			.32	.28				.05		.52			.01			.21	.31						.90				4.74
nt Pleasant,				1.94	.27		.05	.04							.42						.25	.42						.99				4.40
ottstown,				2.25				.38					.05		.40							.60						1.10				4.78
akertown,				1.97	.19			.05	.03				.05		.30						.58	.30						.97				4.44
eading,				1.35	.20			.01	.10				.01		.43			.01			.25	.27					.01	.75				3.39
em Corners,	*	*	*	*	*	*	*							.04				.25	.05			.36						1.44				2.14
eisholtzville,				1.62	.12								.47		.08						.24	.37					1.05					3.95
ppack,				2.25			*	.38					.05	*	.50				*		.50	*	*	*				.53	*	*		4.21
mith's Corner,				1.95	.30								.09		.43						.20	.45						1.05				4.47
warthmore,				1.50											1.17							.80						.57				4.04
West Chester,				1.41	.30			.34	.44				.06	.04	.43						.60	.07						1.07				4.76
Westtown,																																
squehanna Basin.																																
Altoona,			.02	.45	.18																	.09						.68		.06		1.48
educt,			.13	1.52									.08	.16							.25						1.00	.10				3.14
oomsburg,			.09	.96											.01						.22	.10						.06				1.44
e Knob,			.50	.88									.01		.40			.02			.22		.25	.05	.05			.26		.15		2.79
arlisle,				1.42	.54				.04						.22			.02				.62						1.06				2.92
fton,			.04	.42	*	.75						*		.04	.40			.50	.08		.10	.20			.05	*	*	*		*		2.58
Emporium,			.17	.42									.03				.02	.06			.16	.25					.07	.83	.03	.01		2.05
ttysburg,				.70	.66				.25						.17							.31						.88				2.97
rardville,			.04	1.33							.02				.36			.16	.03		.49						.50	.64				3.57
mpian,				.50														.18		.02	.15	.22					.28	.37				1.72
rrisburg,†				1.20	.12			.04	.02						.12			.13			.30	.14						.46		.01		2.54
daysburg,				.63																	.30						.32	.62		.06		2.13
ntingdon,				.90	.08																.23	.15					.05	1.00		.05		2.46
mer,			.06	1.22									.02		.07			.02			.69						.80	.48	.06			3.42
caster,				1.63	.26			.13	.36				.03		.30			.04			.16	.19						.66				3.76
anon,			.02	1.33	.12			.01	.02						.31			.02			.52	.24						.78				3.42
Roy,			.08	.26	.01								.02					.04	.02	.03	.20	.20			.05		.10	1.01	.05			2.07
wisburg,				.77											.16						.05							.73				1.71
Haven,			.12	.47									.01		.05						.05	.17					.25	.40				1.53
Grove,			.54	1.11	.09																.05	.11						.55				2.45
Eaton,			.08	.57											.19			.11			.20	.28						.51				1.94
te College,			.04	.92	.02								.03		.70						.42						.21	.70				3.04
llsboro,			.05	.25																	.35						.10	2.25				3.00
es-Barre,			.20	.75											.27			.12			.24							1.39				2.97
sos,																																
k,				1.11	.41			.48	.18						.33						.26	.15						.63				3.55

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Beaver Dam,																																
Brookville,				.31	.47													.08				.47						.68	.07	.11		2.29
Clarion,			.01	.40	.13												.02	.19	.05	.05		.66		.02	.05			1.01	.06	.09		2.54
Columbus,																																
Confluence,			.02	1.05	.60										.05	.01	.01		.04			.25						.32		.37		2.72
Davis Island Dam,				.22	.10											.01				.05	.08	.32						.55	.02	.06		1.22
DuBois,			.11	.14														.15	.04	.46	.09							1.13	.04	.44		2.60
Freeport,			.03	.19	.20																	.52						.55		.09		1.58
Greensboro,				.62	.33										.07				.16			.25						.33	.02	[illegible]		2.03
Immel Reservoir,			.06	.88														.20			.16	.17						.25				1.72
Indiana,																																
Johnstown,																																
Ligonier,																																
Lock No. 4,			.05	.08	.28											.06		.03	.06			.36		.01				.30	.01	.11		1.35
Mahoning,			.03	.23	.16									.04				.12	.05			.58			.01			1.04	.02	.08		2.36
Meadville,																																
New Castle,																		.20	.05		.37					.02		.70	.05			1.39
Oil City,			.02													.03		.12	.01	.02		.62			.08			.92	.03	.14		1.99
Parker's Landing,			.03	.10	.13									.08		.01		.12	.09			.62		.01	.01			1.19	.02	.06		2.47
Pittsburg,†				.28														.09			.22	.10		.03			.55	.09		.10		1.46
Ridgway,		.10	.21	.21												.01					.61						.09	.03	.05	.14		1.35
Saegertown,			.35										.05		.20	.25		.22	.05		.17	.15	.03				.99	.22	.38			3.04
Saltsburg,			.02	.25	.36									.02		.01		.02	.10			.18						.58		.12		1.66
Shingle House,	*	*		.14									.05			.20		.11	.04	.18	.20	.10		.05				1.10	.02	.07		2.26
Smethport,			.33	.20												.20		.25		.30	.20	.55		.20	.60							2.83
Somerset,			.10	.45											.17									.06			.20	.05	.15			1.18
Stoyestown,			.21	.84											.21	.10			.10		.20	.08		.17			.47	.68	.22	.08		3.36
Uniontown,	*	*		1.15									.02		.06			.14			.18						.57	.05		.17		2.34
Warren,			.40											.01		.19	.01	[illegible]	.02	.10		.52	.05	.10	.20	.02		[illegible]	.05	.30		[illegible]
West Newton,			.07	.10	.25														.11			.30						.30		.14		1.27
Potomac Basin.																																
Chambersburg,																																
McConnellsburg,																																
Lake Basin.																																
Erie,†			.17										.12		.18	.06		[illegible]	.02		.20	.08	.05	.16	.08		.46	.05	.20	.04		[illegible]

† U. S. Weather Bureau Stations. * Missing

Snow.—Altoona, 15th, 22d; Blue Knob, 4th, 14th, 15th, 18th, 21st, 23d, 24th, 25th, 29th, 28th; Hollidaysburg, 15th, 21st; Le Roy, 4th, 19th, 20th, 21st, 24th, 25th, 26th; Quakertown, 15th, 21st, 25th; Emporium, 4th, 15th, 16th, 19th, 20th, 21st, 23d, 24th, 25th, 28th; Mauch Chunk, 15th; State College, 15th, 21st; West Chester, 15th; Coatesville, 15th, 21st; Kennett Square, 15th; Grampian, 20th, 21st; Lock Haven, 19th, 21st; Bloomsburg, 15th, 19th, 20th, 22d, 25th; Saegertown, 15th, 16th, 19th, 23d, 24th; Carlisle, 15th, 22d; Huntingdon, 21st; Kilmer, 15th, 21st; Lancaster, 15th; New Castle, 15th, 26th; Lebanon, 15th, 21st; Coopersburg, 15th, 21st; Drifton, 15th, 19th, 20th, 21st, 22d, 25th; Wilkes-Barre, 15th, 20th, 21st, 25th; Skippack, 15th; Logania, 21st; *Philadelphia* [Centennial Avenue], 15th 20th, 24th, 25th, 27th; Shingle House, 15th, 16th, 19th, 20th, 21st, 24th; Girardville, 15th, 19th, 21st; Selins Grove, 21st; Somerset, 15th, 24th, 28th; Dyberry, 4th, 15th, 21st, 22d; Honesdale, 15th, 21st; South Eaton, 22d; York, 15th, 21st.

Aurora.—Le Roy, 1st; Lebanon, 1st; Selins Grove, 1st; Dyberry, 1st.

Coronæ.—Blue Knob, 26th; Emporium, 18th, 19th, 20th, 22d; Saegertown, 14th; Lebanon, 6th, 19th, 20th, 22d, 23d, 24th; Dyberry, 26th.

Solar Halo.—Le Roy, 1st; Westtown, 1st, 7th; *Philadelphia* [Weather Bureau], 1st, 7th, 29th; [Centennial Avenue], 1st, 7th; Wellsboro, 14th; Dyberry, 7th, 14th.

Lunar Halo.—Hollidaysburg, 18th, 26th; Lancaster, 26th; *Philadelphia*, [Centennial Avenue], 18th, 19th.

Meteors.—Blue Knob, 25th; *Philadelphia* [Centennial Avenue], 10th, 18th, 19th; Dyberry, 30th; State College, 1st, 10th, 16th.

JANUARY WEATHER.

From United States Weather Bureau Records.

The following data, compiled from the records of observations taken during the length of time given at each station, show the average and extreme conditions during that time, and also the range within which weather variations may be expected to keep in any future January.

	Philadelphia. (23 years.)	Pittsburgh. (22 years.)	Erie. (19 years.)
Mean or normal,	32°	31°	28°
Warmest January, Average,	1890 42°	1880 44°	1880 40°
Coldest January, Average,	1893 24°	1875 23°	1875 19°
Highest temperature recorded, Date,	72° 12th, 1890	71° 13th, 1890	73° 1st, 1876
Lowest temperature recorded, Date,	Minus 5° 10th, 1875	Minus 12° 10th, 1875	Minus 15° 10th, 1875
Average date of first "killing" frost,	October 28th	October 21st	October 15th
Average precipitation (inches),	3·40	3·18	3·45
Average number of days with ·01 inch or more,	12	16	20
Greatest monthly precipitation, Date,	5·84 1873	6·17 1888	6·20 1878
Least monthly precipitation, Date,	1·49 1872	1·54 1879	1·41 1875
Greatest amount in 24 hours, Date,	2·24 5th, 1873	2·34 8th, 1884	1·62 27th and 28th, 1889
Greatest amount snowfall in 24 hours, Date,	10·00 5th and 6th, 1893	16·50 8th, 1884	9·00 8th and 9th, 1886
Average number clear days, Partly cloudy, Cloudy,	7 12 12	4 10 17	2 10 19
Prevailing direction of wind,	NW.	W.	SW.
Highest velocity, miles per hour, Date,	52 31st, 1878; 17th, 1885	36 26th, 1882; 1st, 1888	56 9th, 1876

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU

T. F. TOWNSEND, WEATHER BUREAU, L. F. O. IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR DECEMBER, 1893.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 31, 1893.

GENERAL REVIEW.

December's normal temperature and rainfall is about 32°·8 and 3·18 inches. The present month has been 0°·7 colder than the average, and the rainfall 0·12 of an inch less.

The warmest day was the 25th, and the coldest were the 5th and 14th.

With the exception of the 8th, precipitation was reported on every day of the month from some portion of the State. General rains were numerous.

March, 1894, will complete the series of charts (twelve months) showing by isothermal lines the normal temperature of each month. Their publication will be discontinued after that date. The series should be preserved for future reference.

From January 1, 1893, to December 31, 1893, the deficiency in temperature at Philadelphia was 303°; Pittsburgh, 491°; York, 457°, and Erie, 469°.

For the same period the deficiency in precipitation at Philadelphia was 2·91; York, 8·00; Erie, 2·72, and excess at Pittsburgh, 0·36 inch.

	Mean Temperature.	*Mean Precipitation. Inches.*
December, 1887,	31°·5	3·53
1888,	32°·6	3·14
1889,	39°·3	2·77
1890,	27°·5	3·97
1891,	38°·6	4·09
1892,	27°·9	1·69
1893,	32°·1	3·06

TEMPERATURE.

The mean temperature for December, 1893, was 32°·1, which is 0°·7 below the normal, and 4°·2 above the corresponding month of 1892.

The means of the daily maximum and minimum temperatures, 40°·4 and 24°·1, gives a monthly mean of 32°·2, with an average daily range of 16°·3.

Highest monthly mean, 37°·2 at Uniontown.

Lowest monthly mean, 27°·1 at Le Roy and Smethport.

Highest temperature recorded during the month, 70° on the 24th at Easton.

Lowest temperature, minus 7° on the 14th at Dyberry.

Greatest local monthly range, 65° at Drifton.

Least local monthly range, 41° at Chambersburg.

Greatest daily range, 58° at Drifton on the 29th.

Least daily range, 1° at Hamburg, 26th; Chambersburg, 11th.

BAROMETER.

The mean pressure for the month, 30·14, is about ·08 above the normal. At the United States Weather Bureau Stations, the highest observed was 30·88 at Philadelphia, on the 14th, and the lowest 29·47 at Erie on the 16th.

PRECIPITATION.

The average rainfall, 3·06 inches for the month, is a deficiency of 0·12 inch.

The largest monthly totals in inches were Smethport, 6·07; Salem Corners, 4·25; Wellsboro, 4·21; Shingle House, 4·13.

The least were Bloomsburg 1·41; Carlisle, 1·60, and Somerset, 1·75.

WIND AND WEATHER.

The prevailing wind was from the West.

Average number: rainy days, 12; clear days, 6; fair days, 11; cloudy days, 14.

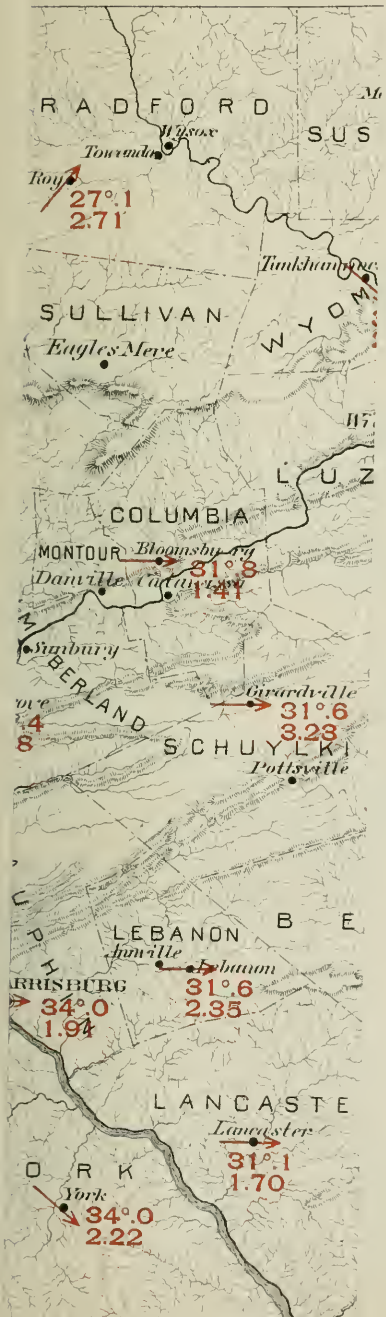
MISCELLANEOUS PHENOMENA.

Thunder.—Hollidaysburg, 25th, 26th; Saegerstown, 25th; Smethport, 25th; Aqueduct, 25th; Selins Grove, 25th; Wellsboro, 25th; Dyberry, 25th; South Eaton, 25th.

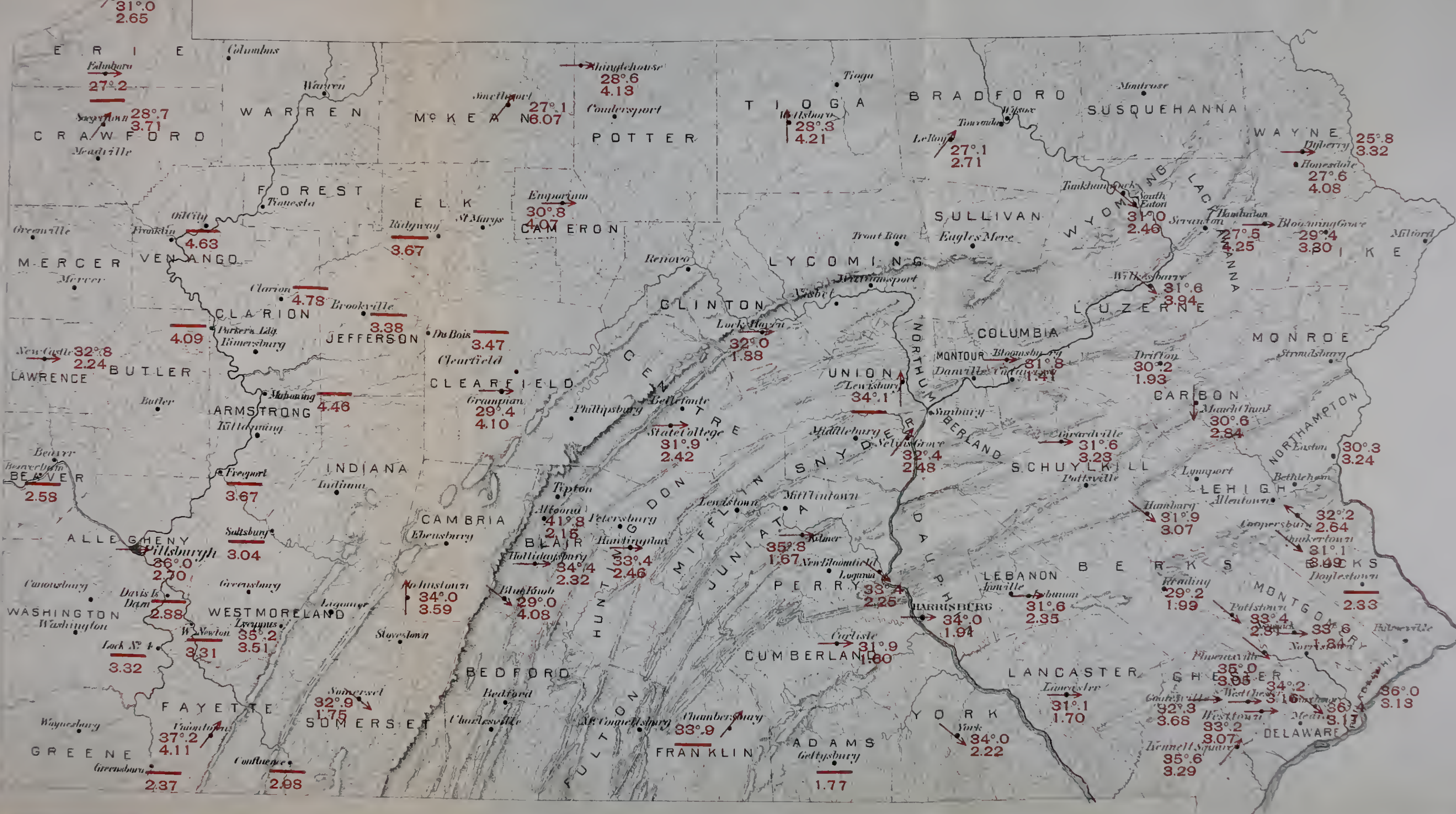
Hail.—Blue Knob, 26th; Westtown, 30th, 31st; Dyberry, 3d, 15th; York, 15th, 28th.

Snow.—Hamburg, 3d, 5th, 15th; Altoona, 3d, 10th, 15th, 28th, 31st; Blue Knob, 1st, 2d, 3d, 4th, 7th, 11th, 13th, 14th, 16th, 17th, 18th, 19th, 26th, 27th, 28th, 30th, 31st; Hollidaysburg, 1st, 3d, 8th, 14th, 16th, 17th, 19th, 30th, 31st; Le Roy, 1st, 3d, 4th, 12th, 13th, 14th, 17th, 18th, 19th, 27th, 28th, 30th, 31st; Quakertown, 5th, 9th, 14th, 30th, 31st; Johnstown, 7th, 10th, 13th, 16th, 17th, 18th, 19th, 20th, 31st; Emporium, 1st, 2d, 3d, 4th, 7th, 9th, 10th, 11th, 12th, 13th, 14th, 16th, 17th, 18th, 19th, 20th, 26th, 27th, 28th, 31st; State College, 3d, 18th, 19th, 28th, 30th, 31st; Coatesville, 3d, 5th, 31st; Kennett

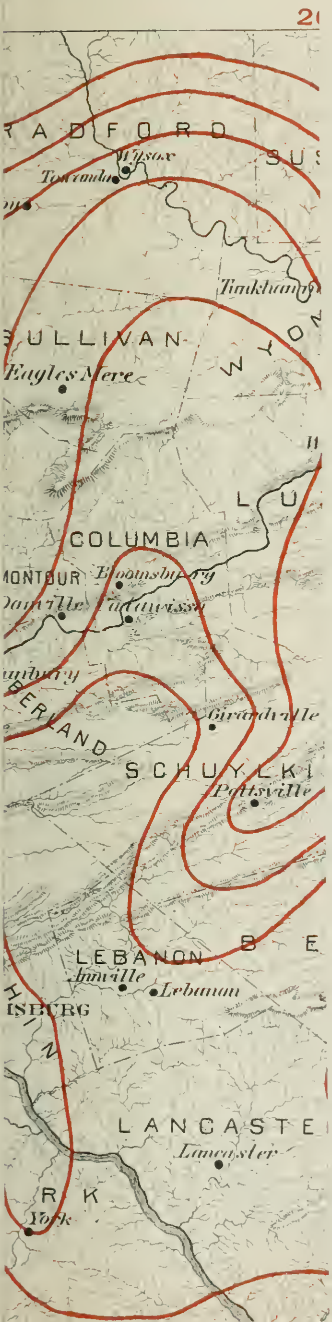
TION FOR DECEMBE



MEAN TEMPERATURE, RAINFALL AND PREVAILING WIND DIRECTION FOR DECEMBER. 1893



DECEMBER.

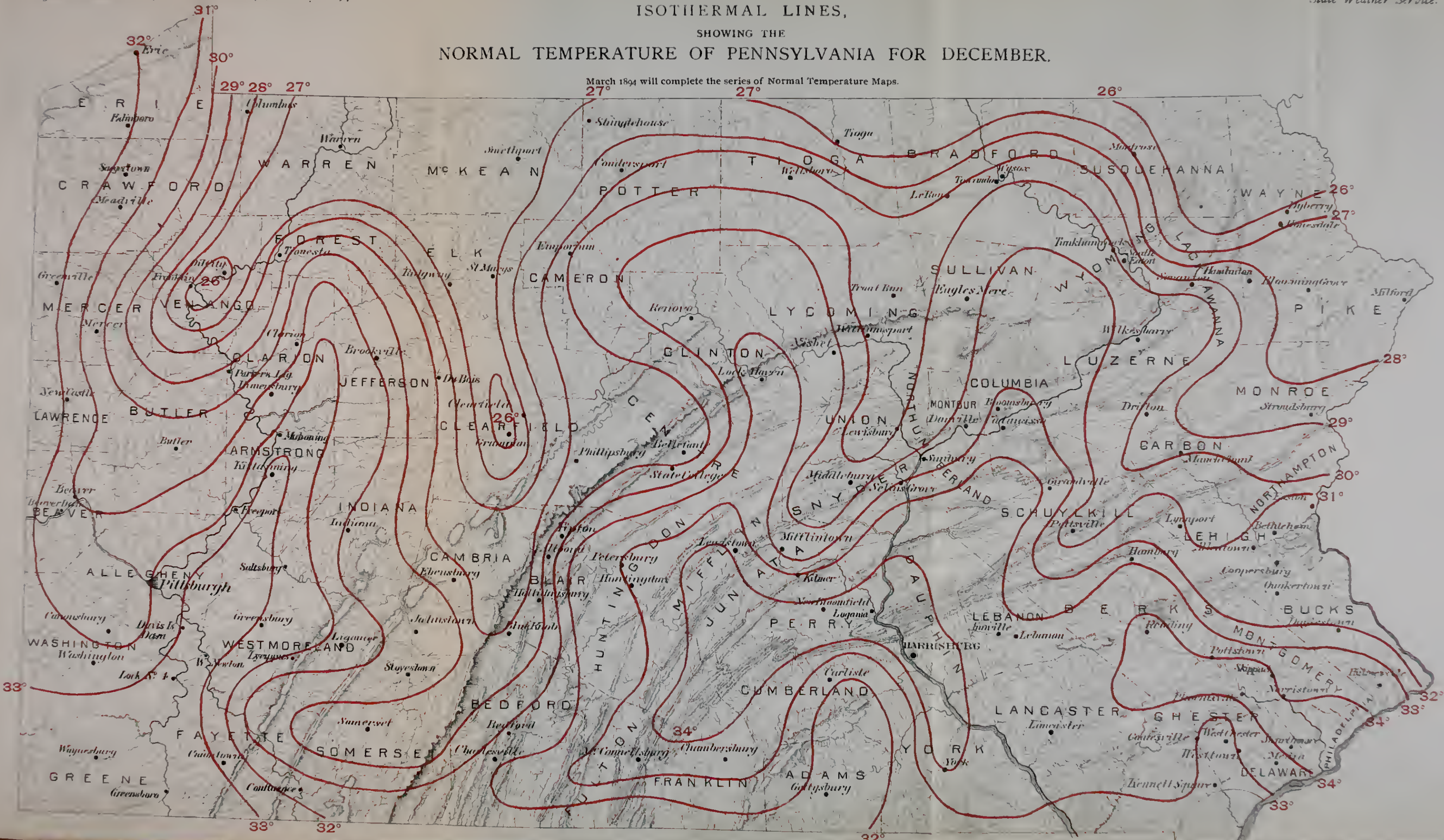

ADFORD
Wysox
Towanda
SUS
ULLIVAN
Eagles Mere
WYO
LU
COLUMBIA
ONTOUR
Bloomsburg
Danville
Catawissa
Girardville
SCHUYLKI
Pottsville
LEBANON
BE
Annville
Lebanon
LANCASTE
Lancaster
York

ISOTHERMAL LINES,

SHOWING THE

NORMAL TEMPERATURE OF PENNSYLVANIA FOR DECEMBER.

March 1894 will complete the series of Normal Temperature Maps.



Service for Decembe

Precipitation.			Num
Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rainfall.	Clear.
. . .	. . .	18	3
. . .	. . .	6	1
. . .	. . .	16	. . .
. . .	. . .	10	. . .
14·7	2·5	16	. . .
. . .	. . .	11	5
. . .	. . .	. . .	. . .
10·2	0·8	19	. . .
. . .	. . .	14	9
5·8	. . .	13	6
4·2	1·0	21	2
15·3	1·0	19	. . .
8·8	1·0	14	14
4·2	1·2	12	3
5·5	. . .	14	13
10·5	. . .	11	10
6·5	2·5	14	12
5·7	. . .	16	10
5·2	1·5	8	7
14·0	. . .	14	1
7·5	0·5	6	4
2·4	1·0	9	6
. . .	. . .	. . .	. . .
15·3	0·5	16	2
2·5	1·0	8	10
3·1	. . .	12	7
8·0	. . .	10	2
16·0	2·0	. . .	8
. . .	. . .	23	. . .
2·2	. . .	11	12
. .	. . .	. .	20
. . .	. . .	. . .	. . .
3·5	. . .	10	12
. . .	. . .	. . .	. .
5·3	0·3	8	3
5·0	. . .	6	7
8·8	0·5	8	1
10·0	1·0	11	8
8·1	. . .	15	11
11·0	2·0	5	8
12·5	3·0	12	15
26·0	. . .	16	. . .
8·0	. . .	7	13
. . .	. . .	. . .	. . .
8·8	. .	11	. . .
5·0	0·3	8	8
3·5	. . .	13	8
4·8	. . .	13	6
9·0	3·0	7	. . .
21·9	. .	19	. . .
14·8	3·0	11	4
7·2	1·2	9	. . .
3·2	. . .	8	1
14·5	0·5	12	1
5·0	. . .	. . .	2
. . .	. . .	. . .	. . .
19·2	2·0	12	2
23·5	3·0	12	. . .
18·2	3·0	15	2
. . .	0·6	11	. . .
. . .	. . .	. . .	. . .
8·0	2·0	10	2
8·2	2·0	10	11

Absence of numerals indicates that

Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for December, 1893.

County.	Station.	Elevation above Sea Level (feet).	Barometer Reduced to Sea Level. Mean.	Barometer Highest.	Barometer Lowest.	Temperature. Mean.	Maximum. Highest.	Maximum. Date	Minimum. Lowest.	Minimum. Date.	Mean of Maximum.	Mean of Minimum.	Daily Range. Mean.	Daily Range. Greatest.	Daily Range. Date	Daily Range. Least.	Daily Range. Date.	Relative Humidity.	Dew Point.	Precipitation. Total Inches	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rainfall.	Number of Days. Clear.	Fair.	Cloudy.	Wind. Prevailing Direction. 7 A. M.	2 P. M.	9 P. M.	Observers.
Allegheny,	Pittsburgh, A.	820	30·15	30·80	29·57	36·0	64	24	15	2	43·6	27·6	16·0	33	3	7	17	78·0	30·0	2·70	...	...	18	3	11	17	W	...	W	O. D. Stewart, Weather Bureau
Berks,	Hamburg.	380	...	...	...	31·9	57	25	7	6	38·0	25·8	12·2	25	6, 8, 25	1	26	...	...	3·07	...	...	6	1	23	7	NW	...	NW	W[illegible] Shipe
Berks,	Reading, A	280	...	...	...	29·2	...	...	...	...	...	...	...	...	...	...	...	...	...	1·99	...	...	16	...	...	...	...	...	...	Franklin Yager
Blair,	Altoona, B,	1,181	...	...	...	41·8	63	25, 26	20	5	41·4	34·2	15·2	33	26	6	29	...	...	2·15	...	...	10	...	...	...	...	...	...	Dr. C. B. Dudley
Blair,	Blue Knob, A,	2,500	...	...	...	29·0	53	15, 16, 25	7	2	35·3	22·6	12·7	28	2, 25	6	24, 26	...	...	4·08	14·7	2·5	16	...	16	15	NW	...	NW	A. H. Boyle
Blair,	Hollidaysburg,[1]	947	...	...	...	34·4	65	24	6	5	42·4	22·2	20·2	37	21	9	31	...	...	2·32	...	...	11	5	14	12	W	W	W	Prof. J. A. Stewart.
Bradford,	Wysox[1],	718	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Charles Beecher.
Bradford,	Le Roy,	1,400	...	...	...	27·1	53	25	6	5	33·3	21·0	12·3	28	15	2	13, 30	...	...	2·71	10·2	0·8	19	...	13	18	SW	SW	SW	G. W. T. Warburton
Bucks,	Forks of Neshaminy[1] 26 days	304	...	...	...	34·1	...	...	...	...	...	...	...	...	...	...	...	...	...	2·97	...	...	14	9	6	9	W	W	W	J. C. Hilsman.
Bucks,	Quakertown,[1]	536	30·16	30·81	29·51	31·1	63	25	9	6, 8, 14	40·5	22·2	18·3	33	7	8	5	...	...	3·49	5·8	...	13	6	17	8	NW	SW	NW	J. L. Heacock.
Cambria,	Johnstown, A,	1,184	30·19	30·81	29·54	34·0	62	15	[illegible]	21	42·1	25·9	16·2	17	21	5	22	...	...	3·59	4·2	1·0	21	2	10	19	S	...	S	E. C. Lorentz.
Cameron,	Emporium, A,	1,050	30·09	30·78	29·44	30·8	57	25	1	5	39·2	22·4	16·8	35	21	7	2, 22, 30	84·0	22·2	4·07	15·3	1·0	19	...	9	22	W	...	W	T. B. Lloyd.
Carbon,	E. Mauch Chunk,	550	...	...	...	30·6	65	25	9	6, 8, 14	38·8	22·5	16·3	34	6, 25	4	3	...	...	2·84	8·8	1·0	14	14	4	13	N	...	...	F. C. Wintermute.
Centre,	State College[1]— Agricultural Experiment Station,	1,191	30·10	30·78	29·44	31·9	60	24, 25	11	8, 20	39·9	23·6	16·3	42	26	7	22, 30	82·3	26·8	2·42	4·2	1·2	12	3	13	15	W	W	W	Prof. Wm. Frear.
Chester,	West Chester,[1]	455	30·15	30·85	29·47	34·2	63	25	13	6, 14	43·0	26·9	16·1	28	26	7	5, 11	71·0	25·7	3·26	5·5	...	14	13	6	12	S	W	W	J. C. Green, D.D.S.
Chester	Coatesville,[1]	380	...	...	...	32·3	62	25	7	6	44·4	23·4	21·0	38	7	3	30	...	...	3·68	10·5	...	11	10	11	10	W	W	W	W. T. Gordon.
Chester	Kennett Square, A,	275	...	...	...	35·6	68	25	9	6	40·3	24·8	21·5	33	25	12	16, 31	...	...	3·29	6·5	2·5	14	12	11	8	SW	...	SW	B. P. Kirk.
Chester	Phœnixville, A,	190	30·17	30·88	29·50	35·[illegible]	64	25	9	8	43·7	26·4	17·3	28	6	7	5	79·0	25·6	3·05	5·7	...	16	10	7	14	NW	...	NW	Knowles Croskey
Chester,	Westtown (27 days),	350	...	...	...	33·2	61	25	11	14	40·9	25·4	15·5	25	15	5	22	...	...	3·07	5·2	1·5	8	7	6	11	W	...	W	Harry Alger.
Clearfield,	Grampian,*[1]	1,450	...	...	...	29·4	56	25	6	8	34·4	24·0	10·4	24	8, 21	4	3, 17, 30	...	...	4·10	14·0	...	14	1	11	19	W	W	W	Nathan Moore.
Clinton,	Lock Haven,[1]	560	...	...	...	32·[illegible]	62	25	11	7, 14, 21	38·2	23·0	15·2	35	21	3	30	...	...	1·88	7·5	0·5	6	4	11	16	W	W	W	Prof. J. A. Robb.
Columbia,	Bloomsburg, A— State Normal School,	500	...	...	...	31·8	59	25	11	5	39·5	24·2	15·3	[illegible]	27	2	29	79·5	24·1	1·41	2·4	1·0	9	6	9	16	W	...	NW	Prof. J. G. Cope.
Crawford	Meadville— Divinity Hall.[1]	1,200	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Chas. Graves.
Crawford	Saegerstown, A,	1,200	...	...	...	23·7	60	25	−2	5	38·3	17·1	21·2	35	8	6	31	...	...	3·71	15·3	0·5	16	2	8	21	SW	...	SW	J. G. Appe
Cumberland,	Carlisle,[1]	480	...	...	...	31·9	65	25	15	6	40·6	24·9	15·7	34	25	5	10, 17	...	...	1·63	2·5	1·0	8	10	9	12	W	W	W	J. E. Pague.
Dauphin,	Harrisburg, A.	361	30·17	30·85	29·57	34·0	63	25	15	6	40·0	27·0	13·0	29	25	3	17	79·0	27·0	1·91	3·2	...	12	7	14	10	W	W	W	F. Ridgway, Weather Bureau
Delaware	Swarthmore, A— Swarthmore College,	190	30·13	30·86	29·49	36·4	59	16	14	14	43·3	29·4	13·9	26	7	3	18	74·9	29·8	3·17	8·0	...	10	2	18	11	SW	...	NW	Prof. Susan J. Cunningham.
Erie,	Edinboro,*	1,420	...	...	...	27·2	56	25	8	2	...	...	...	...	...	...	...	...	...		16·0	2·0	...	8	4	19	W	...	...	C. F. Sweet.
Erie,	Erie, A,	681	30·10	30·78	29·47	31·0	62	25	4	2	37·0	25·0	12·0	24	15	4	20	78·0	25·0	2·65	...	...	23	...	9	22	SW	...	SW	P. Wood, Weather Bureau.
Fayette,	Uniontown,[1]	1,000	...	...	...	37·2	61	25	15	2	44·1	30·3	13·8	27	14	5	10	...	...	4·11	2·2	...	11	12	11	8	SW	SW	SW	Wm. Hunt
Franklin,	Chambersburg,[2]	618	...	...	...	33·9	59	25	18	13	40·6	27·2	13·4	25	23	1	11	...	...	...		...		20	5	6	NW	SW	SW	G. W. Ludwig
Fulton,	McConnellsburg,[1]	875	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	T. F. Sloan.
Huntingdon	Huntingdon, A— The Normal College,	650	...	...	...	33·4	66	24	10	21	42·5	24·4	18·1	38	21	7	31	...	...	2·46	3·5	...	10	12	8	11	W		W	Prof. W. J. Swigart.
Indiana	Indiana— State Normal School,	1,350	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Prof. S. C. Schmucker.
Juniata	Kilmer,[3]	475	...	...	...	35·8	65	25	19	8	...	...	...	...	...	...	...	...	...	1·67	5·3	0·3	8	3	17	11	W	...	...	R. J. Mickey.
Lancaster,	Lancaster, A— (24 days.) Franklin and Marshall College,	413	30·17	30·77	29·53	31·1	68	16	7	6	38·6	23·6	15·0	37	16	3	23	77·5	24·2	1·70	5·0	...	6	7	10	7	W	...	W	W. E. Bushong.
Lawrence,	New Castle,[1]	932	...	...	...	32·8	62	25	4	2	40·4	22·9	17·5	33	26	6	10	...	...	2·24	8·8	0·5	8	1	9	21	NW	W	NW	Wm. T. Butz.
Lebanon,	Lebanon, A,	458	30·12	30·82	29·54	31·6	61	25	2	6	40·5	22·8	17·7	35	6	10	19, 20	89·3	26·0	2·35	10·0	1·0	11	8	13	10	SW	...	W	G. W. Hayes, C. E.
Lehigh	Coopersburg,[1]	520	...	...	...	32·2	61	25	11	14	40·8	24·8	16·0	20	6	5	17	...	...	2·64	8·1	...	13	11	9	11	SE	SW	SE	Dr. M. H. Boye.
Luzerne,	Drifton (25 days), A,	1,683	30·18	30·81	29·53	30·2	69	29	4	16	44·8	15·6	29·2	58	29	10	9	80·0	25·0	1·93	11·0	2·0	5	8	7	10	...	...	...	J. R. Wagner
Luzerne	Wilkes-Barre, A,	575	...	...	...	31·6	58	25, 26	9	6	41·[illegible]	22·3	18·7	38	26	6	22	...	...	3·94	12·5	3·0	12	15	5	11	NW	...	NW	A. W. Betterly
McKean,	Smethport, A,	1,500	...	...	...	27·1	57	25	−4	5	34·4	19·8	14·6	33	15	3	31	...	...	6·07	26·0	...	16	...	15	16	SW	...	SW	Armstrong & Brownell.
Montgomery,	Pottstown,	150	...	...	...	33·4	62	25	10	6	40·8	26·1	14·7	32	25	5	3	78·3	26·0	2·81	8·0	...	7	13	8	10	NW	NW	NW	Charles Moore, D. D. S.
Montgomery	[illegible]ppack, A,	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	B. W. Dambly
Northampton,	Easton— Lafayette College,	325	...	...	...	30·3	70	24	6	7, 8	38·2	21·4	16·8	38	24	3	25	...	...	3·24	8·8	...	11	...	...	...	...	...	...	J. W. Moore
Perry	Aqueduct (Logania),*[1]	367	...	...	...	33·4	68	25	12	5	...	...	...	...	...	...	...	...	...	2·25	5·0	0·3	8	8	13	10	NW	...	...	Richard Call[illegible]
Philadelphia	U. S. Weather Bureau, A.	117	30·16	30·88	29·50	36·6	62	16	17	14	42·9	29·8	13·1	25	15	5	30	74·0	28·0	3·13	3·5	...	13	6	15	8	SW	...	...	L. M. Dey, Weather Bureau.
Philadelphia	1529 Centennial Avenue, A,	120	30·16	30·88	29·49	37·0	61	16	17	14	44·1	29·9	14·2	26	26	6	5	74·0	27·1	3·30	4·8	...	13	6	16	9	SW	...	NW	John C[illegible]
Pike	Blooming Grove,*[1]	...	...	...	...	20·4	55	23, 24	10	13	...	...	...	...	...	...	...	...	...	3·30	9·0	3·0	7	...	...	...	...	...	...	John Grathwohl.
Potter	[illegible]gle House,	1,475	...	...	...	23·6	56	25	−3	5	37·2	19·9	17·3	41	26	5	22	...	...	4·13	21·9	...	19	...	9	22	W			C. D. Voorhees, M. D.
Schuylkill	Girardville (28 days),	1,000	30·13	30·79	29·44	31·6	61	25	14	14	40·0	25·4	14·6	28	15	3	30	...	...	3·23	14·8	3·0	11	4	18	6	W	W	W	E. C. Wagner.
Snyder	Selins Grove, A,	455	30·12	...	...	32·4	61	25	8	5	40·6	24·3	16·3	33	6	8	3, 18, 30	88·1	27·2	2·48	7·2	1·2	9	...	18	13	SW	...	SW	J. M. Boyer.
Somerset,	Somerset,	2,250	...	...	...	32·9	58	16, 24, 25	4	14	40·6	22·1	18·5	46	14	3	17	...	...	1·75	3·2	...	8	1	1	29	NW	NW	NW	W. M. Schrock.
Tioga	Wellsboro,*	1,327	...	...	...	28·3	60	25	−3	5	...	...	...	...	...	...	...	...	...	4·21	14·5	0·5	12	1	5	25	S	S	S	H. D. Deming
Union	Lewisburg (21 days), A,	450	...	...	...	34·1	75	15	11	14	43·4	24·8	18·6	53	15	8	23	90·8	29·6	...	5·0	...	...	2	14	5	S	...	S	Prof. W. G. Owens.
Warren	Columbus,	1,410	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Wm. Loveland
Wayne	Dyberry,[1]	1,100	...	...	...	25·8	57	25	−7	11	34·9	16·0	18·9	38	6	7	11	...	...	3·32	19·2	2·0	12	2	12	17	W	W	NW	Theodore Day
Wayne	Honesdale,[1]	1,000	...	...	...	27·6	55	25	−1	14	35·7	19·2	16·5	32	6, 8	6	11, 30	...	...	4·08	23·5	3·0	12	...	...	...	...	...	...	John Torrey
Wayne	(Salem Corners) Hamlinton,[1]	1,600	...	...	...	27·5	57	25	4	13	33·6	22·1	11·5	23	8	5	23	...	...	4·25	18·2	3·0	15	[illegible]	10	19	W	W	W	T. B. Orchard, M. D.
Westmoreland	(Immel Reservoir) Lycippus,*[1]	1,420	...	...	...	35·2	57	25	11	3	42·5	28·0	14·5	34	4	2	6, 8	...	...	3·51	...	0·6	11	...	...	...	...	...	...	Murray Forbes
Westmoreland	Ligonier,	1,750	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	J. T. Ambrose.
Wyoming	South Eaton, A	6[illegible]	...	...	...	31·0	59	25	6	5, 6	40·1	21·8	18·3	39	26	7	30	...	...	1·46	8·0	2·0	10	2	14	15	NW	...	...	R. M. Hart
York	York, A,	385	30·25	30·81	29·60	34·0	63	25	3	6	43·1	24·9	18·2	33	6, 25	5	17	89·0	30·2	2·22	8·2	2·0	10	11	9	11	NW	...	NW	Mrs. L. H. Grenewald

[illegible] Observations taken at 8 A. M. and 8 P. M. B, Observations taken at 12 Noon. *Extremes from dry thermometers. [1] Mean temperatures, 7 + 2 + 9 + 9 ÷ 4. Mean of 8 + 8 + 2. [3] Mean of 7 + 7 + 2. Absence of numerals indicates that mean of temperature is from maximum and minimum readings.

5	6	7	8	9	10	11	
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. .	. .	. .	. .	·04	. .	·02	.
. .	. .	. .	. .	. .	·14	. .	[illegible]
. .	. .	. .	. .	. .	·16	. .	[illegible]
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. .	. .	. .	. .	. .	·08	·17	.
. .	. .	. .	. .	. .	·25	·10	[illegible]
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. .	. .	. .	. .	·04	·16	. .	.
. .	. .	. .	. .	·31	. .	. .	.
. .	. .	. .	. .	. .	·39	·02	[illegible]
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PRECIPITATION DURING DECEMBER, 1893.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin.																																
Blooming Grove,			·60	1·18										·70	·12						·05			·45						·20		3·30
Browers Lock,	·06		·42	·55	·28	·04			·16	·04					·23		·66						·08						·08	·42	·11	3·13
Coatesville,	·04		·77	·21	·55				·15						·29	·90						·12	·03					·05		·57		3·68
Coopersburg,	·05		·85	·18	·40				·09	·01				·03	·18	·50						·02	·04	·03					·11	·10	·07	2·64
Doylestown,	·11		·76	·25	·34				·16	·04					·09	·21						·04							·13	·15	·05	2·33
Dyberry,			·96	·30	·17									·45	·38	·10							·15			·40		·02	·16	·10	·13	3·32
Easton,	·04		·25	1·12	·40	·14				·08					·67											·37	·01		·06		·10	3·24
Forks of Neshaminy,	·10		1·08		·16				·16	·02					·27	·78						·04	·02		·02			·02	·08	·18	·04	2·97
Frederick,	·04		·88	·23	·34				·14	·04					·25	·68							·06						·13	·17	·03	2·99
Hamburg,			1·40		·42										·33	·58						·02									·32	3·07
Honesdale,			1·53		·23									·60	·56	·10			·06				·12		·02			·03	·60	·08	·15	4·08
Kennett Square,	·03		·55	·25	·45				·13	·03					·30	·80						·10	·01					·04	·04	·52	·04	3·29
Lansdale,		·10	·83	·15	·40				·16	·03					·23	·80						·04							·12	·14	·05	3·05
Mauch Chunk,	·02		·94	·32	·28				·01	·02					·36	·42						·03	·07			·14		·05	·07		·11	2·84
Ottsville,		·10	·01		·80	·15			·11						·14	·78	·02					·05	·07	·04					·20			3·07
Philadelphia, a†	·05		·35	·52	·24				·15	·01					·25	1·03						·01	·01					·03		·44	·04	3·13
Philadelphia, b,	·05		·45	·52	·23				·15	·01					·24	1·09						·02	·02					·04		·51	·03	3·36
Phœnixville,	·06		·68	·21	·22	·06			·15	·04					·28	·83						·09	·06	·03				·03	·05	·10	·16	3·05
Point Pleasant,	·07		1·12	·08	·41				·18					·01	·25	·72					·03	·04	·02					·03	·17	·14	·03	3·30
Pottstown,			·95		·80					·16					·23	·55						·06								·06		2·81
Quakertown,	·06		·95	·20	·50				·14	·07					·30	·67						·09		·04					·16	·26	·05	3·49
Reading,	·01		·57	·25	·20				·02					·01	·08	·45						·04	·02	·01		·01		·01	·11	·14	·06	1·99
Salem Corners,			·04	·33		·35									·98	·08	·27		·02	·05			·16		·09	·50		·01	·15	·02	·30	4·25
Seisholtzville,			·92		·36										·34	·45													·21		·23	2·51
Skippack,			·41	·10	·21				·09							·50							·03				*	*	*	*	*	1·34
Smith's Corner,	·08		·92	·25	·31				·17	·04				·03	·29	·77						·03	·04	·05					·22	·10	·09	3·39
Swarthmore,	[illegible]		·60		·40					·27					·15	·85						·03	·07					·02		·38		3·17
West Chester,	·04		·69	·20	·29				·09	·01					·27	·75						·12	·06					·02	·04	·55	·03	3·16
Westtown,			·71		·25				·20				*		·25	·73					*	·17				*		·16		·60		3·07
Susquehanna Basin.																																
Altoona,			·78							·01					·94				·01				·02	·02		·10		·05	·18		·04	2·15
Aqueduct,			1·15											·19	·12	·13										·07		·17	·09	·13		2·25
Bloomsburg,			·92	·09										·07	·06							·04	·02						·12	·07	·02	1·41
Blue Knob,	·22		·67				·02		·02					·10	1·16	·13	·20	·10	·30				·04		·02			·31	·51	·05	·25	4·08
Carlisle,			·44	·35											·28	·08												·01	·14	·28	·16	1·60
Drifton,			*	·30	·40					*							*							*	*			·20	·53	·20	*	1·93
Emporium,	·12		1·01				·03		·02	·16	·02	·01		·21	·93	·18	·03	·15	·10	·07			·22	·01		·26			·46		·08	4·07
Gettysburg,			·39	·31		·13									·14		·17						·06						·13		·44	1·77
Girardville,		·27	·83		·81	*								·24	·17	·43						·06						·02	·07	·17	·16	3·23
Grampian,	·12		1·18							·10			·02	·24	1·04	·22		·14					·07	·16	·05	·14		·11	·50			4·10
Harrisburg,†			·76	·17	·02					·04				·02	·21	·29						·01	·02						·15	·15	·07	1·91
Hollidaysburg,		·11	·76							·04					·96	·03			·04							·09		·08	·12	·04	·05	2·32
Huntingdon,			·90							·02				·05	·95	·05							·05					·18	·16	·05	·05	2·46
Kilmer,		·90	·03											·10	·32	·08												·19	·02	·03		1·67
Lancaster,			·03	·05	·35										·23	·43						·01			*	*	*	*	*	*	*	1·70
Lebanon,			·95		·28									·03	·21	·45					·01		·03	·04					·12	·10	·07	2·35
Le Roy,	·05		1·31	·01						·04		·02		·20	·24	·05	·03	·02	·03				·05	·02	·02	·30		·04	·22	·03	·05	2·71
Lewisburg,																																
Lock Haven,			1·04											·30		·02		·05											·38	·09		1·88
Selins Grove,			·36											·20	·06	1·34										·25		·05	·10	·10	·02	2·48
South Easton,			·89	·11	·14										·32	·19							·06	·02		·42			·12		·19	2·46
State College,			1·09							·02				·03	·76	·10						·01	·03			·04		·05	·16	·05	·08	2·42
Wellsboro,	·05		1·20						·02		·05			·55	1·50	·24		·15	·10						·10				·20		·05	4·21
Wilkes-Barre,			1·98		·22					·10				·42	·26	·33			·04				·06		·18			·05	·05		·25	3·94
Wysox,																																
York,			·67	·13	·30				·05						·14	·40						·03	·01						·07	·42		2·22

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Beaver Dam,			·86	·20						·07					·99	·10						·13	·06	·03	[illegible]			·11				2·58
Brookville,			·34	·18						·11					·79	·18	·04		·33	·08		·17	·12	·07	·22	·05		·02	·58			3·38
Clarion,	·25	·03	1·20	·20	·02					·20		·05	·05	·01	·98	·20	·12	·03	·08	·18			·09	·08	·22	·18		·15	·32		·12	4·78
Columbus,																																
Confluence,	·01	·02	·30	·35						·09					·76	·03	·01		·01	·01		·02	·03	·09	·05			·14	[illegible]	·22	·12	[illegible]
Davis Island Dam,		·08	·93	·12							·08				·90	·10	·04					·05	·05	[illegible]	[illegible]			[illegible]	·60	[illegible]		[illegible]
DuBois,	·03	·02	·10				·03								1·10	·12	·21	·03	·15	·08				·10	·13			[illegible]	·42	[illegible]		[illegible]
Freeport,	·05		1·06	·05						·06					1·48	·05	·19	·04	·01			[illegible]	·10		[illegible]			·22	·25		[illegible]	[illegible]
Greensboro,		·03	·50	·15						·10					·65	·05	·13					[illegible]		·03				·10	[illegible]	·10	[illegible]	[illegible]
Immel Reservoir,	·15		·89							·09					1·00	·25		·06				·10	[illegible]			·04			·32		[illegible]	[illegible]
Indiana,																																
Johnstown,	·07	·06	1·09						·02	·04				·05	1·23	·12	·09	·02	·07	[illegible]	·01	·02	·02		[illegible]	[illegible]		·07	[illegible]	[illegible]	[illegible]	3·59
Ligonier,																																
Lock No. 4,	·02		·65	·23						·08					1·19	·06	·12	·03	·01			·05	[illegible]	·06	·06	[illegible]		·08	·43	[illegible]	[illegible]	[illegible]
Mahoning,	·03	·02	1·29	·14						·10					1·31	·09	·11	·02	·05	·01			·11	·06	·19	·16		·27	·45		[illegible]	4·46
Meadville,																																
New Castle,	·04	·06	·20	·13					·04		·02				·98		·05	[illegible]	·12				[illegible]	·05	[illegible]			·30			·06	[illegible]
Oil City,	·22	·05	·89	·20						·14		·01	·01		1·04	·17	·09	·08	·40	·30		·04	·13	·05	[illegible]			·10	·58	·02	[illegible]	[illegible]
Parker's Landing,	·08	·02	1·16	·16						·16		·02			1·04	·10	·11	·03	·16	·03			·14	[illegible]	·07	·15		·24	·30	·02	·08	[illegible]
Pittsburg,†	·04	·05	·74	·01					·05				·05	·01	·94	·12	·06		·02		·02	·03	·15		[illegible]			[illegible]	·30			[illegible]
Ridgway,		·80	·15						·17				·10	·80	·42	·10	·01	·08				·18	[illegible]	[illegible]	·15			[illegible]		·05		[illegible]
Saegerstown,				·25	·31				·10				·03	·42	1·27	·15	·10	·10	·15				·25		·05	·15		·19	[illegible]		[illegible]	[illegible]
Saltsburg,	·04	·05	·85	·22						·03					1·00	·06	·07	·01	·01	·02		·03	·03	[illegible]	[illegible]	·04		·05	[illegible]	[illegible]	[illegible]	[illegible]
Shingle House,	·31		·61	·07						·08	·17			·60	·72	·08	·03	·15	·30	·05			·21	[illegible]	[illegible]	·38		·03	[illegible]		[illegible]	[illegible]
Smethport,	·45		1·10	·10						·25	·10	·15		·45	1·35	·85		·20	·02				·25	[illegible]		[illegible]			·25		[illegible]	[illegible]
Somerset,	·04		·25												·35	·03	·12		·09		·05								[illegible]			[illegible]
Stoyestown,		·44	·37	·89					·04	·16					·86		·20	·10	·12		·03			·12		·17			[illegible]	·12	[illegible]	[illegible]
Uniontown,	·02		·69						·31					·11	1·37	·26						·06				·05		[illegible]	[illegible]		[illegible]	[illegible]
Warren,	·41	·19	1·24	·15						·39	·02	·08	·03	·04	1·31	·11	·19	·10	·10	·19	·03	·04	·30	·11	·06	[illegible]	·03	·08	[illegible]	[illegible]	[illegible]	[illegible]
West Newton,	·03		·60	·34						·05					1·10	·02	·16	·10				·07		[illegible]		[illegible]		·05	[illegible]	[illegible]		[illegible]
Potomac Basin.																																
Chambersburg,																																
McConnellsburg,																																
Lake Basin.																																
Erie,†	·12	·06	·54	·01			·04		·15	·06	·08			·09	·38	·14	·18	·08	·08			[illegible]	·03	[illegible]	[illegible]	[illegible]		·10	[illegible]	[illegible]	[illegible]	2·65

† U. S. Weather Bureau Stations. * Missing

Square, 3d, 5th, 30th; Phœnixville, 3d, 5th, 6th, 14th, 19th, 28th, 30th, 31st; Lock Haven, 3d, 14th, 18th, 30th; Bloomsburg, 4th, 14th, 15th, 17th, 28th, 30th, 31st; Saegerstown, 3d, 7th, 13th, 14th, 17th, 18th, 19th, 28th. 31st; Carlisle, 3d, 14th, 30th; Harrisburg, 3d, 5th, 14th, 30th, 31st; Uniontown, 1st, 2d, 31st; Huntingdon, 3d, 14th, 31st; Kilmer, 2d, 14th, 18th, 28th, 30th, 31st; Lancaster, 3d, 5th; New Castle, 1st, 2d, 4th, 11th, 17th, 18th, 19th, 31st; Lebanon, 3d, 5th, 14th, 15th, 19th, 30th, 31st; Drifton, 4th, 5th, 28th, 30th; Wilkes-Barre, 3d, 5th, 10th, 14th, 27th, 31st; Smethport, 1st, 3d, 4th, 11th, 12th, 14th, 15th, 18th, 19th, 31st; Pottstown, 4th, 5th, 30th; Aqueduct, 3d, 14th, 28th, 30th; *Philadelphia* [Centennial Avenue], 3d, 5th, 14th, 19th, 28th, 30th; Shingle House, 1st, 3d, 4th, 11th, 14th, 17th, 18th, 19th, 20th, 28th, 31st; Girardville, 2d, 3d, 5th, 14th, 28th, 30th, 31st; Selins Grove, 3d, 14th, 30th, 31st; Somerset, 1st, 3d, 16th, 18th, 20th, 29th; Dyberry, 3d, 5th, 14th, 15th, 28th, 30th, 31st; Honesdale, 3d, 5th, 14th, 19th, 30th, 31st; Salem Corners, 3d, 4th, 6th, 15th, 19th, 20th, 28th, 30th, 31st; South Eaton, 1st, 3d, 5th, 18th, 19th, 22d; York, 3d, 5th, 6th, 9th, 14th, 19th, 30th, 31st.

Sleet.—Altoona, 15th, 26th; Blue Knob, 1st, 3d, 14th, 26th; Hollidaysburg, 3d, 28th; Le Roy, 5th; Emporium, 15th; Coatesville, 2; Lock Haven, 14th, 29th, 30th; Saegerstown, 14th; Kilmer, 3d, 14th; *Philadelphia* [Centennial Avenue], 14th, 28th, 30th, 31st; Shingle House, 3d, 9th; Dyberry, 3d, 15th; York, 15th, 28th.

Aurora.—Westtown, 29th; Shingle House, 5th.

Coronæ.—Blue Knob, 15th; Emporium, 19th; Saegerstown, 17th, 18th; Lebanon, 16th, 17th, 18th, 21st.

Lunar Halo.—Hollidaysburg, 15th; Phœnixville, 15th; Westtown, 22d; Lancaster, 15th, 16th; Girardville, 20th; Dyberry, 24th.

Meteors.—State College, 7th, 10th; *Philadelphia* [Centennial Avenue], 6th, 13th.

Parhelias.—Blue Knob, 6th; Dyberry, 2d.

FEBRUARY WEATHER.

From United States Weather Bureau Records.

The following data, compiled from the records of observations taken during the length of time given at each station, show the average and extreme conditions during that time, and also the range within which weather variations may be expected to keep in any future February.

	Philadelphia. (22 years.)	Pittsburgh. (23 years.)	Erie. (20 years.)
Mean or normal,	34°	33°	28°
Warmest February, Average,	1890 41°	1871 43°	1882 37°
Coldest February, Average,	1885 24°	1875 22°	1875 16°
Highest temperature recorded, Date,	75° 23d, 1874	76° 16th, 1883	70° 16th, 1883
Lowest temperature recorded, Date,	Minus 2° 5th, 1886	Minus 10° 15th, 1875	Minus 16° 9th, 1875
Average date of first "killing" frost,	October 28th	October 21st	October 15th
Average precipitation (inches),	3·28	2·90	3·55
Average number of days with ·01 inch or more,	12	15	17
Greatest monthly precipitation, Date,	5·70 1884	6·52 1887	8·50 1887
Least monthly precipitation, Date,	0·84 1877	0·85 1871	0·33 1877
Greatest amount in 24 hours, Date,	1·84 16th, 1873	2·01 26th, 1887	3·35 3d and 4th, 1883
Greatest amount snowfall in 24 hours, Date,	8·00 3d, 1886	5·30 25th, 1885	3·50 27th, 1887
Average number clear days, Partly cloudy, Cloudy,	7 10 11	4 11 13	4 10 14
Prevailing direction of wind,	NW.	NW.	S.
Highest velocity, miles per hour, Date,	48 2d, 1876; 3d and 23d, 1880; 26th, 1886	40 26th, 1887	64 1875

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

T. F. TOWNSEND, WEATHER BUREAU, L. F. O. IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR JANUARY, 1894.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 31, 1894.

GENERAL REVIEW.

January's normal temperature and rainfall is about 28°·6 and 3·47 inches. The present month has been 4°·1 warmer than the average, and the rainfall 1·18 less.

The warmest days were the 4th, 5th, 23d and 24th, and the coldest on the 26th.

While the precipitation was 1·18 below the average it was well distributed throughout the month and occurred on numerous days.

The snowfall was comparatively light and very little occurred until the latter part of the month.

The greatest amounts reported on ground January 31st were Shingle House, 14·0; Kane, 13·0; Blue Knob, 13·0, and Drifton, 12·0 inches.

Many stations reported none.

From January 1, 1894, to January 31, 1894, the excess in temperature at Philadelphia was 139°; Pittsburgh, 227°; and Erie, 202°.

For the same period the deficiency in precipitation at Philadelphia was 1·59; Erie, 1·45, and Pittsburgh, 1·21.

	Mean Temperature.	*Mean Precipitation Inches.*
January, 1888,	22°·1	4·19
1889,	31°·9	3·54
1890,	37°·7	3·04
1891,	30°·6	3·64
1892,	26°·3	4·77
1893,	19°·3	2·85
1894,	32°·7	2·29

TEMPERATURE.

The mean temperature for January, 1894, was 32°·7, which is 4°·1 above the normal, and 13°·4 above the corresponding month of 1893.

The means of the daily maximum and minimum temperatures, 40°·6 and 25°·0, give a monthly mean of 32°·8, with an average daily range of 15°·6.

Highest monthly mean, 40°·6 at Altoona.

Lowest monthly mean, 26°·6 at Dyberry.

Highest temperature recorded during the month, 65° on the 23d at Somerset.

Lowest temperature, minus 9° on the 26th at Shingle House.

Greatest local monthly range, 63° at Smethport.

Least local monthly range, 39° at Harrisburg.

Greatest daily range, 52° at Drifton and Saegerstown.

BAROMETER.

The mean pressure for the month, 30·16, is about ·06 above the normal. At the United States Weather Bureau Stations, the highest observed was 30·67 at Philadelphia, on the 18th, and the lowest 29·35 at Philadelphia on the 30th.

PRECIPITATION.

The average rainfall, 2·29 inches for the month, is a deficiency of ·18.

The largest monthly totals in inches were Kane, 4·71; Shingle House, 64; Smethport, 4·20; Clarion, 4·19; Stoyestown, 4·12.

The least were Selins Grove, 0·83; Beaver Dam, 0·96; Altoona, 0·99.

WIND AND WEATHER.

The prevailing wind was from the West.

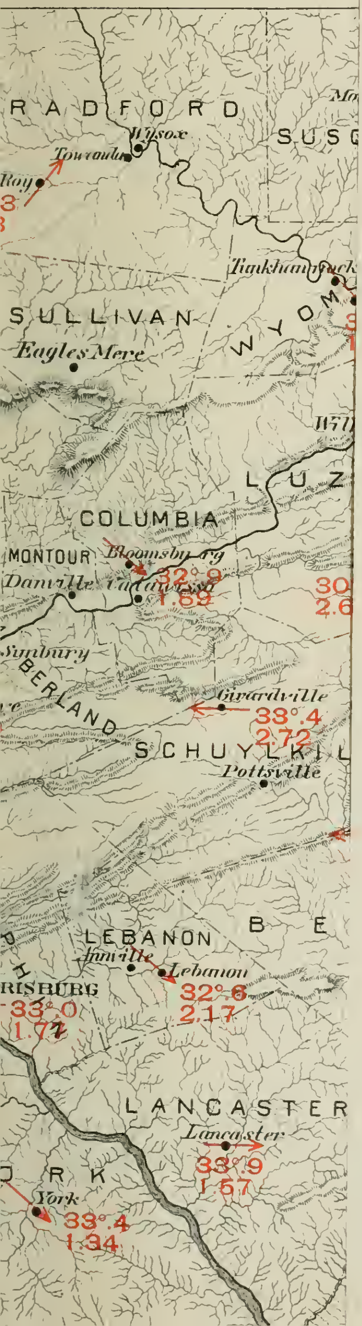
Average number: rainy days, 10; clear days, 9; fair days, 9; cloudy days, 13.

MISCELLANEOUS PHENOMENA.

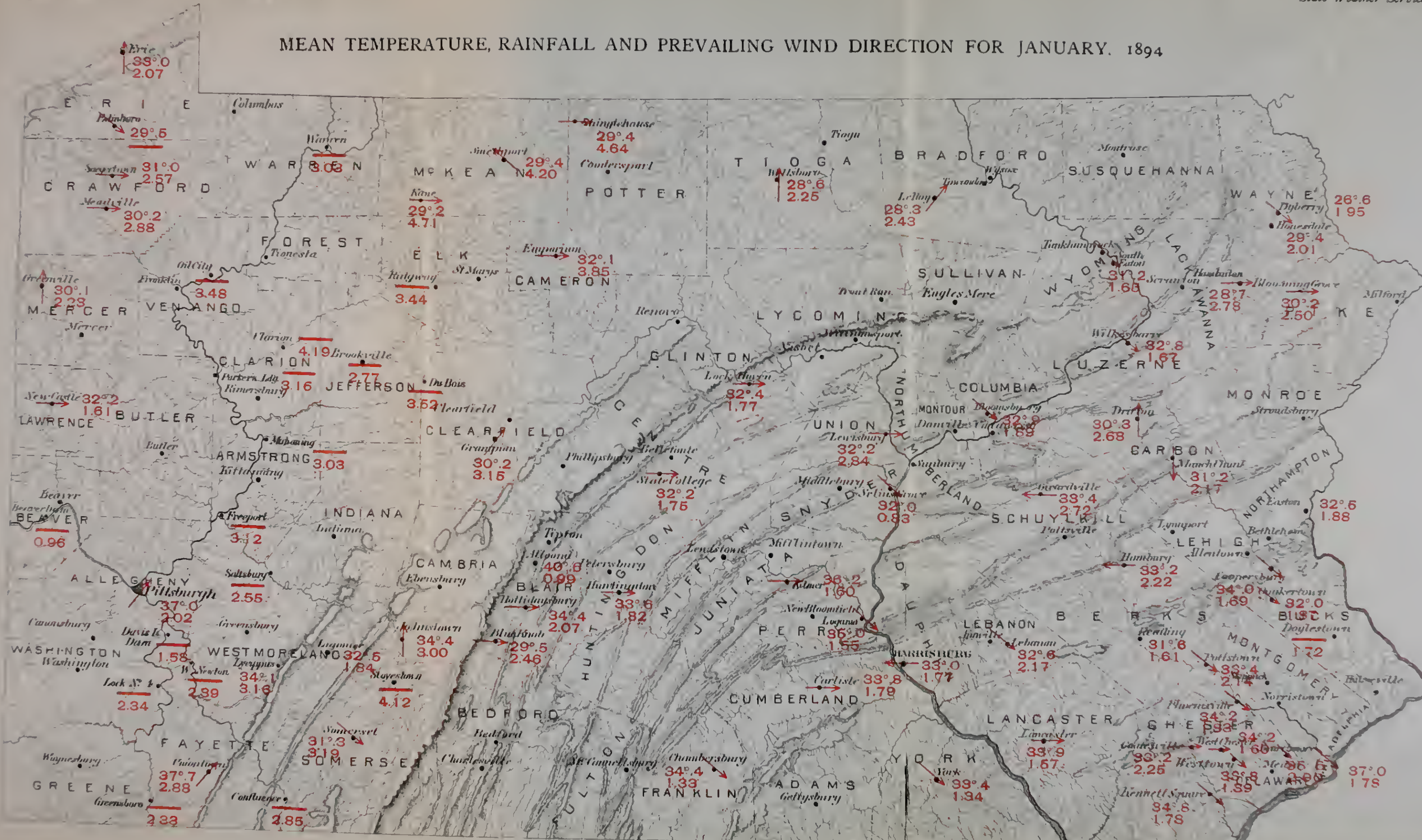
Thunder.—Shingle House, 25th.

Hail.—Emporium, 21st; Bloomsburg, 11th, 24th, 30th; Dyberry, 6th.

TION FOR JANUARY.



MEAN TEMPERATURE, RAINFALL AND PREVAILING WIND DIRECTION FOR JANUARY, 1894



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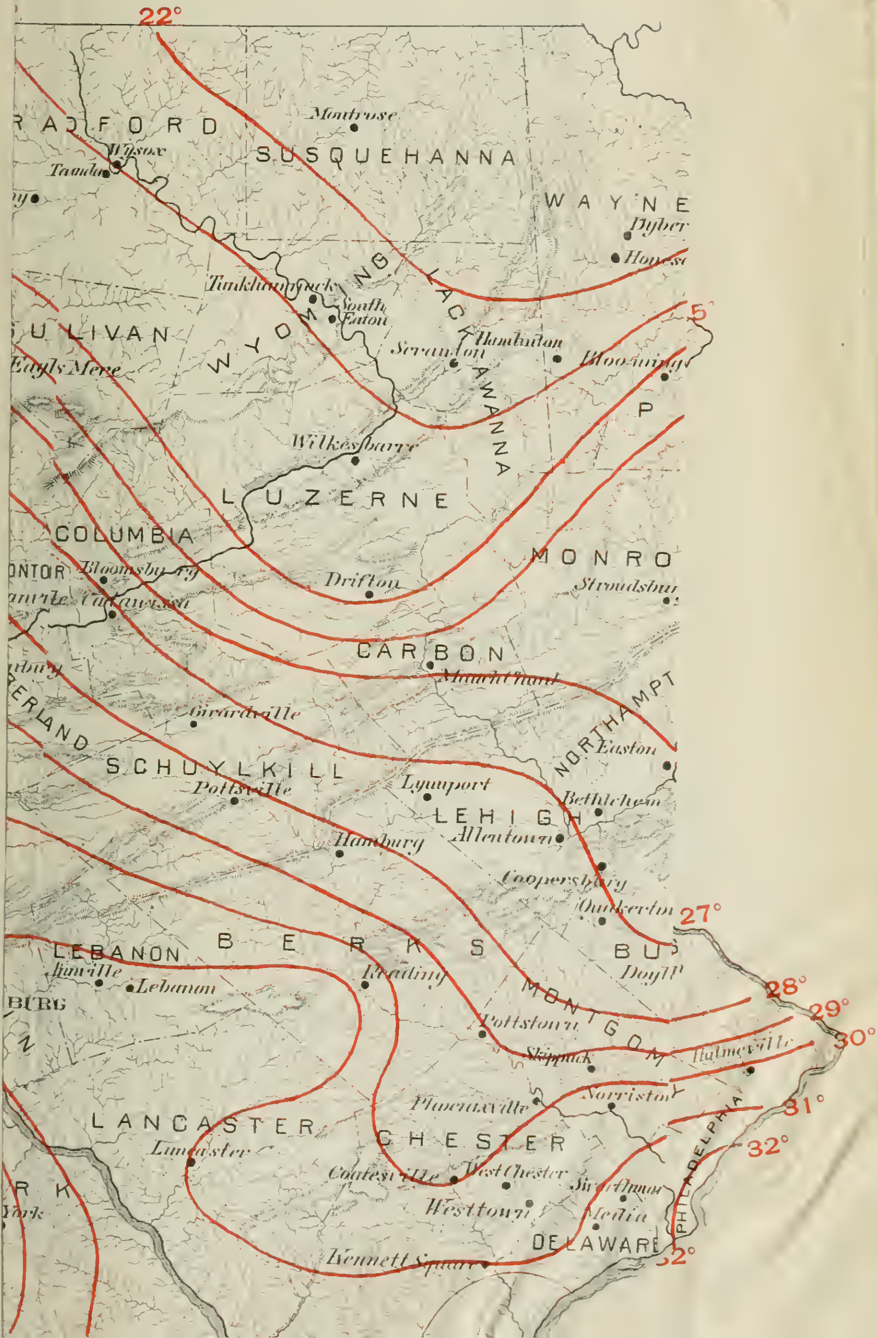
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South Eaton
SULIVAN
Eagls Mere
Scranton
Hamlinton
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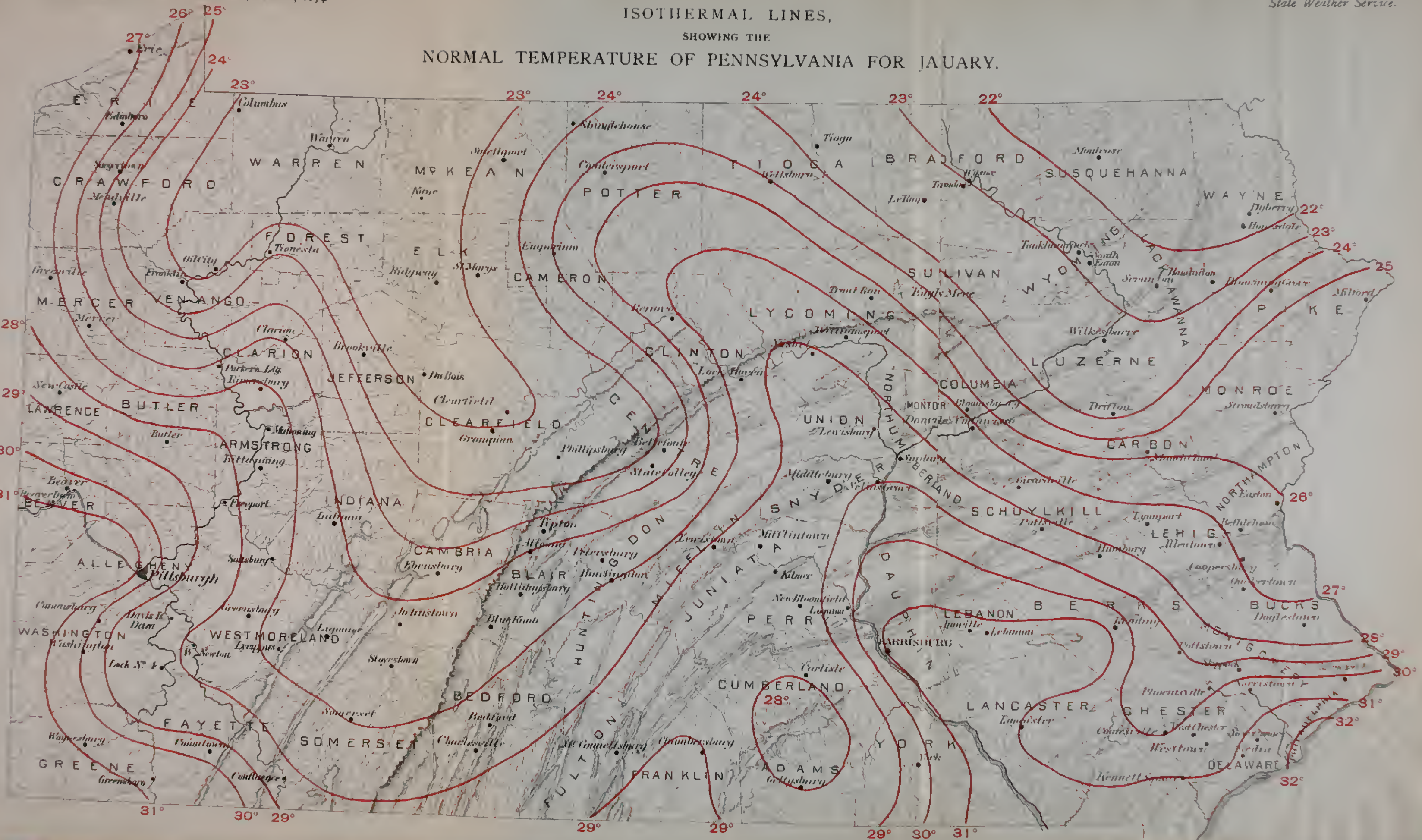
5°
P
Wilkesbarre
LUZERNE
COLUMBIA
MONRO
NTOUR
Bloomsburg
Catawissa
Drifton
Stroudsbur
CARBON
Mauch Chunk
NORTHAMPT
Girardville
Easton
ERLAND
SCHUYLKILL
Pottsville
Lynnport
Bethlehem
LEHIGH
Allentown
Hamburg
Coopersburg
Quakertown
27°
LEBANON
BERKS
BU
Doyl
Lebanon
Reading
28°
29°
MONTGOM
Pottstown
Skippack
Holmesville
30°
Norristown
Phoenixville
31°
LANCASTER
CHESTER
32°
Lancaster
Coatesville
West Chester
Westtown
Media
PHILADELPHIA
DELAWARE
Kennett Square
32°
York

State Weather Service.

ISOTHERMAL LINES,
SHOWING THE
NORMAL TEMPERATURE OF PENNSYLVANIA FOR JAUARY.



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Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for January, 1894

County.	Station	Elevation above Sea Level (feet).	Temperature. Mean.	Maximum. Highest.	Maximum. Date.	Minimum. Lowest.	Minimum. Date.	Mean of Maximum.	Mean of Minimum.	Daily Range. Mean.	Daily Range. Greatest.	Precipitation. Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rain or Snow.	Number of Days. Clear.	Fair.	Cloudy.	Wind. Prevailing Direction.	Observers.
Allegheny, . .	Pittsburgh, ...	820	37.0	60	18	10	25	45.1	29.2	15.9	30	2.02	1.8	0.5	11	8	12	11	SW	O. D Stewart, W. B.
Berks, ...	Hamburg, ...	380	33.2	53	23	12	26	39.8	26.7	13.1	24	2.22	3.0	2.0	7	6	13	12	E	William Shipe.
Berks, . . .	Reading,[2]	280	31.6	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	1.61	. . .	. . .	15	. .	. .	. .	. . .	Franklin Yager.
Blair, ...	Altoona, ...	1,181	40.6	62	6	18	26	47.8	33.4	14.4	33	0.99	. . .	. . .	6	. .	. .	. .	. . .	Dr. C. B. Dudley.
Blair, ...	Blue Knob, ...	2,500	29.5	52	5	3	25	34.0	25.0	9.0	20	2.46	16.5	13.0	12	6	11	13	W	A. H. Boyle.
Blair, ...	Hollidaysburg (30 days), . . .	947	34.4	61	5	9	13	43.8	25.0	18.8	33	2.07	4.0	4.0	10	9	10	11	W	Prof. J. A. Stewart.
Bradford, . .	Le Roy, ...	1,400	28.3	55	5	5	26	34.2	22.4	11.8	20	2.43	10.2	10.0	12	4	16	11	SW	G. W. T. Warburton.
Bucks, ...	Forks of Neshaminy[1] (30 days),	304	35.8	. . .	. . .	. . .	. . .		. . .	. . .	. . .	1.82	. . .	. . .	12	7	14	9	W	J. C. Hilsman.
Bucks, ...	Quakertown, ...	536	32.0	57	25	11	26, 28	40.4	23.6	16.8	38	1.87	3.1	3.0	10	6	16	9	NW	J. L. Heacock.
Cambria, . .	Johnstown, ...	1,184	34.4	59	5	8	26	42.3	26.6	15.7	26	3.00	7.5	4.0	15	5	8	18	S	E. C. Lorentz.
Cameron, . .	Emporium, ...	1,050	32.1	57	5	3	26	40.2	24.0	16.2	27	3.85	9.1	6.0	12	7	17	7	W	T. B. Lloyd.
Carbon, . . .	E. Mauch Chunk, ...	550	31.2	56	5	10	26	38.9	23.5	15.4	26	2.17	6.0	2.0	10	15	5	11	N	F. C. Wintermute.
Centre, ...	State College—Agricultural Experiment Sta.,	1,191	32.2	58	5	11	26	39.2	25.2	14.0	28	1.75	6.7	5.0	8	6	12	13	W	Prof. Wm. Frear.
Chester, . . .	West Chester, ...	455	34.2	56	24	13	26	40.6	27.9	12.7	24	1.60	4.0	1.0	10	14	3	14	W	J. C. Green, D.D.S.
Chester, . . .	Coatesville, ...	380	33.2	55	24	6	28	42.4	23.9	18.5	31	2.25	7.0	1.0	10	10	8	13	W	W. T. Gordon.
Chester . . .	Kennett Square, ...	275	34.8	57	24	8	28	43.2	20.4	16.8	31	1.78	3.2	0.5	10	15	2	14	NW	B. P. Kirk.
Chester. . .	Phœnixville, ...	190	34.2	56	24, 25	9	28	41.3	27.1	14.2	34	1.83	3.5	. . .	16	8	6	17	NW	Knowles Croskey.
Chester, . . .	Westtown (20 days), ...	350	33.8	57	24	12	28	40.8	26.7	14.1	28	1.39	3.5	0.5	5	6	5	9	NW	Harry Alger.
Clearfield, . .	Grampian, ...	1,450	30.2	54	5	4	13, 26	36.4	24.0	12.4	30	3.15	14.0	10.0	9	4	18	9	SW	Nathan Moore.
Clinton, . . .	Lock Haven,[1]	560	32.4	60	5	9	26	39.5	23.3	16.2	30	1.77	4.0	4.0	9	7	7	17	W	Prof. J. A. Robb.
Columbia, . .	Bloomsburg,—State Normal School, ...	500	32.9	57	5	13	26	40.2	25.6	14.6	34	1.89	6.2	5.0	23	12	6	13	NW	Prof. J. G. Cope.
Crawford, . .	Meadville—Divinity Hall (30 days), . . .	1,200	30.2	55	4	—1	26	39.8	20.7	19.1	30	2.88	5.0	. . .	. . .	. .	. .	. .	W	Prf. J. H. Montgomery.
Crawford, . .	Saegerstown, ...	1,200	31.0	54	4	—5	26	40.0	22.1	17.9	52	2.57	6.4	. . .	8	6	7	18	W	J. G. Apple.
Cumberland, .	Carlisle, ...	480	33.8	56	5, 14	15	26	41.5	26.1	15.4	30	1.79	3.0	2.0	11	10	10	11	W	J. E. Pague.
Cumberland, .	Carlisle—Dickinson College (22 days),	480	33.6	54	6	15	26	41.6	25.6	16.0	32	. . .	. . .	. . .	. . .	. .	. .	.	. . .	Prof. C. F. Himes.
Dauphin, . .	Harrisburg, ...	361	33.0	54	5	15	26	40.0	27.0	13.0	22	1.77	2.5	.	12	8	14	9	E	F. Ridgway, W. B.
Delaware, . .	Swarthmore—Swarthmore College, ...	190	35.6	55	24, 25	11	28	41.7	29.4	12.3	32	2.00	. . .	. . .	. . .	8	11	12	NW	Prof. S. J. Cunningham.
Erie, ...	Edinboro,*[1]	1,400	29.5	50	4	4	26	. . .	. . .	. . .	. . .	. . .	10.0	7.0	. . .	14	12	5	NW	C. F. Sweet.
Erie, ...	Erie, ...	681	33.0	54	4	9	26	39.0	27.0	12.0	28	2.07	. . .	. .	17	4	12	15	S	P Wood, W. B.
Fayette, . . .	Uniontown, ...	1,000	37.7	62	5, 24	5	25	46.2	29.2	17.0	35	2.88	8.8	. . .	11	14	11	6	SW	Wm. Hunt.
Franklin, . .	Chambersburg, ...	618	34.4	60	5	16	26	41.0	27.7	13.3	28	1.33	2.0	1.0	7	. .	. .	. .	NW	David Rhea.
Fulton, ...	McConnellsburg, ...	875	. . .	. . .	. . .	. . .		. . .	. .	. . .	. . .	. . .	. . .		. . .	. .	. .	. .	. .	T. F. Sloan.
Huntingdon, .	Huntingdon—The Normal College, ...	650	33.6	62	5	11	26	43.2	23.9	19.3	34	1.82	3.0	2.0	7	12	6	13	W	Prof. W. J. Swigart.
Indiana, . . .	Indiana—State Normal School, ...	1,350	. . .	. . .	. . .	. . .	. . .		. . .	. .	. . .	. . .	. . .	. . .	. . .	. .	. .	. .	. . .	Prof. S C. Schmucker.
Juniata, . . .	Kilmer,[1]*	475	36.2	56	5	18	26	. . .	. . .	. . .	. . .	1.60	2.8	1.0	8	9	10	12	W	R. J. Mickey.
Lancaster, . .	Lancaster— [22 days. Franklin and Marshall Col'ge,	413	33.9	55	23	15	26	41.8	26.0	15.8	28	1.57	5.5	1.5	7	9	3	10	W	W. E. Bushong.
Lawrence, . .	New Castle, ...	932	32.2	56	5	3	26	40.8	23.5	17.3	36	1.61	3.2	. . .	6	10	8	13	W	Wm. T. Butz.
Lebanon, . . .	Lebanon, ...	458	32.6	54	23	9	28	40.4	24.9	15.5	26	2.17	4.7	2.3	14	9	13	9	NW	G. W. Hayes, C.E.
Lehigh, . . .	Coopersburg, ...	520	34.0	58	23	13	26	41.8	26.3	15.5	26	1.69	3.8	2.0	13	11	10	10	NW	Dr. M. H. Boye.
Luzerne, . . .	Drifton (27 days), ...	1,683	30.3	60	27	3	22	48.6	12.0	36.6	52	2.68	16.5	12.5	10	10	7	10	N	J. R. Wagner.
Luzerne, . . .	Wilkes-Barre, ...	575	32.8	56	24	11	10, 26	42.0	23.7	18.3	36	1.67	8.5	6.0	11	6	11	14	NW	A. W. Betterly.
McKean, . . .	Kane (29 days), ...	2,000	29.2	50	5	4	26	36.6	21.7	14.9	26	4.71	23.0	13.0	10	8	8	13	W	C. H. Kemp.
McKean, . . .	Smethport, ...	1,500	29.4	55	5	—8	26	37.4	21.5	15.9	33	4.20	16.0		7	. .	20	11	SE	Armstrong & Brownell
Mercer, . . .	Greenville—Thiel College (19 days), . .	1,000	30.1	51	15	5	13	37.0	23.2	13.8	37	2.23	6.5	0.8	6	11	2	6	S	Prof. S. H. Miller.
Montgomery,	Pottstown, ...	150	33.4	55	23	9	28	40.2	26.6	13.6	25	2.14	10.5	1.0	8	14	3	14	NW	Charles Moore, D.D.S.
Montgomery, .	Skippack, ...	. . .	. . .	. . .	. . .	. . .	. . .	. . .		. . .	. . .	. . .	. . .	. .	. . .		. .	. .	. . .	B. W. Dambly.
Northampton,	Easton—Lafayette College, ...	325	32.6	55	24	13	26, 28	39.4	25.8	13.6	35	1.88	6.5	. . .	14	8	12	12	. . .	J. W. Moore.
Perry, ...	(Aqueduct) Logania, ...	367	35.0	60	5	14	28	42.7	27.4	15.3	30	1.55	2.2	1.2	11	11	7	13	NW	Richard Callin.
Philadelphia, .	U S. Weather Bureau, ...	117	37.0	58	24	17	26	42.3	30.9	11.4	22	1.78	4.1	. . .	14	9	6	16	NW	L. M. Dey, W. B
Philadelphia, .	1529 Centennial Avenue, . . .	120	36.9	57	24	17	26	43.0	30.8	12.2	33	1.85	5.3	. . .	14	8	12	11	NW	John Comly.
Philadelphia, .	3911 Locust Street, ...	120	35.9	56	24	17	26	42.4	29.4	13.0	31	2.11	5.0	. .	15	10	3	18	W	R. L. Paddock.
Pike, ...	Blooming Grove,*[1]	. . .	30.2	56	5	5	26	.	. . .	. .	. . .	2.50	15.0	9.0	5	5	12	14	W	John Grathwohl.
Potter, ...	Shingle House, ...	1,475	29.4	53	4, 5	—9	26	37.8	21.1	16.7	34	4.64	17.7	14.0	14	14	4	13	W	C D. Voorhees, M.D.
Schuylkill, . .	Girardville,[1] (30 days), ...	1,000	33.4	53	16	12	26	39.2	27.6	11.6	23	2.72	12.0	10.5	11	8	5	17	E	E. C Wagner.
Snyder, . . .	Selins Grove, ...	455	32.0	48	4, 23	13	13, 28	39.4	24.6	14.8	23	0.83	3.0	2.0	6	. .	22	9	NW	J. M. Boyer,
Somerset, .	Somerset, ...	2,250	31.3	65	23	3	25	39.8	22.8	17.0	35	3.19	15.0	6.0	9	10	3	18	NW	W. M. Schrock.
Tioga, ...	Wellsboro,*[1]	1,327	28.6	60	5	4	26		. .	. . .	. . .	2.25	10.5	10.5	10	7	8	16	S	H. D. Deming
Union, . . .	Lewisburg, ...	450	32.2	59	5	11	11	41.2	23.2	18.0	28	2.84	3.6	. .	9	5	9	17	W	Prof. W. G. Owens.
Wayne, . . .	Dyberry, ...	1,100	26.6	53	5	2	1, 2	35.3	17.8	17.5	37	1.95	11.0	7.0	13	7	7	17	NW	Theodore Day.
Wayne, . . .	Honesdale, ...	1,000	29.4	54	5	6	2	37.7	21.0	16.7	38	2.01	11.0	8.0	14	. .	.	. .	.	John Torrey.
Wayne, . . .	(Salem Corners) Hamlinton, .	1,600	28.7	52	5	4	26	34.4	23.0	11.4	21	2.78	11.6	6.0	14	11	3	17	W	T.B. Orchard, M D.
Westmoreland,	(Immel Reservoir) Lycippus, .	1,420	34.1	58	5, 28	7	26	41.6	26.6	15.0	48	3.16	8.5	. . .	10	. .	. .	. .	. . .	Murray Forbes
Westmoreland,	Ligonier (22 days), ...	1,750	32.5	60	24	2	26	43.4	21.6	21.8	40	1.84	7.0	5.0	3	2	9	11	. . .	C. D. Ambrose.
Wyoming, . .	South Eaton, ...	660	31.2	55	5	9	26	39.5	22.8	16.7	34	1.65	8.0	8.0	12	10	9	12	NW	B. M. Hall.
York, ...	York, ...	385	33.4	55	23	12	2	41.2	25.6	15.6	25	1.34	3.5	2.0	14	13	8	10	NW	Mrs. L. H. Grenewald.

Mean temperature from maximum and minimum readings. *Extremes from dry thermometers. [1] Mean temperatures, 7 + 2 + 9 + 9 + 4. [2] Mean temperature 8 + 8 + 8.

7	8	9	10	11	12	13	14	15	16	17	18	1
. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	·0
. .	. .	. .	. .	. .	·03	·02	. .	. .	·33	. .	. .	·1
·06	. .	. .	. .	. .	·09	·01	. .	·01	·27		. .	·2
. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	.
·05	. .	. .	. .	. .	·20	. .	. .	. .	·24	·04	. .	·2
·02	. .	. .	. .	. .	·01	. .	. .	. .	·49	·03	. .	·0
. .	. .	. .	. .	. .	·17	. .	. .	. .	·21	. .	. .	.
. .	. .	. .	. .	. .	·01	. .	. .	. .	·50	·01	. .	·0
. .	. .	. .	. .	. .	·10	. .	. .	. .	·45	. .	. .	·1
. .	. .	. .	. .	·05	·02	. .	. .	·05	·12	·02	. .	·3
*	*	*	*	*	*	. .	. .	·42	. .	. .	·24	.
.	. .	. .	. .	·04	. .	. .	. .	. .	·62	. .	. .	·2
.	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	.
·02	. .	. .	. .	·03	·08	. .	. .	. .	·32	·01	.	·2
.	. .	. .	. .	. .	. .	. .	. .	·33	·04	. .	·24	.
*	*	*	. .	. .	. .	. .	. .	. .	. .	. .	. .	.
	. .	. .	. .	·04	. .	. .	. .	. .	·32	. .	. .	·1
.	.	. .	. .	. .	·05	·02	. .	. .	·35	·02	. .	·2
.	. .	. .	. .	. .	. .	*	. .	·38	. .	. .	. .	.
.	. .	. .	. .	. .	. .	. .	. .	·49	. .	. .	·07	
.	. .	. .	. .	. .	·10	. .	. .	. .	·32	. .	. .	·3
·04	. .	. .	. .	. .	·08	. .	. .	. .	32	. .	. .	·2
.	.	. .	. .	·02	. .	. .	. .	·14	·34	. .	·02	·0
.	. .	. .	. .	·05	. .	. .	. .	·01	. .	. .	·17	.
.	. .	. .	. .	. .	·05	·05	. .	·65	. .	. .	. .	.
·01	. .	. .	. .	. .	·03	. .	. .	. .	·46	·01	. .	·1
.	. .	. .	. .	·05	·05	. .	. .	·22	·05	. .	·05	·1
.	. .	. .	. .	. .	. .	. .	. .	. .	·25	·30	. .	.
.	. .	. .	. .	·15	. .	. .	. .	·25	·10	. .	·15	.
.	. .	. .	. .	·10	·10	. .	. .	. .	·26	·04	·12	.
.	. .	. .	. .	·41	. .	. .	·16	. .	·06	. .	·04	·1
.	·02	. .	. .	. .	·10	·01	. .	·03	·44	·04	. .	·3
.	. .		. .	·07	. .	. .	. .	. .	·34	·02	. .	·2
.	. .	. .	. .	.	. .	. .	. .	. .	·16	. .	. .	.
.	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	.
·01	. .	. .	. .	. .	·01	. .	. .	·44	·06	. .	·15	·0

PRECIPITATION DURING JANUARY, 1894.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin.																																
Blooming Grove,										·20			·20		1·00											·20				·50		2·50
Browers Lock,					·05					·03	·06				·03	·09			·08		·06	·04			·09		·39		·25	·08		1·85
Coatesville,					·10						·10				·05				·06		·10			·10		·05	·40		·54	·75		2·25
Coopersburg,					·06					·08					·02	·09			·06		·11	·01		·06	·03	·03	·25		·37	·52		1·69
Doylestown,					·06					·05	·08				·02	·10				·06	·05				·04		·34		·49	·43		1·72
Dyberry,					·16	·08				·04	·04			·14	·14	·16			·10		·05			·20			·09		·34	·41		1·95
Easton,					·02	·01				·05	·02				·04	·09			·08		·07			·02	·08	·35	·17		·39	·49		1·88
Forks of Neshaminy,					·05					·05	·08				·02	·09			·06		·03			·02	·15		·29		·45	·53		1·82
Frederick,					·06					·05	·03					·11			·11		·09				·08		·20		·20	·59		1·52
Hamburg,					·21					·04					·18						·19			·21		·17			1·22			2·22
Honesdale,					·12	·07				·05	·04			·14	·18	·18			·09		·07			·09	·14		·09		·27	·48		2·01
Kennett Square,					·07						·06				·03	·07			·04		·10			·02			·45		·28	·06		1·78
Lansdale,					·21					·07	·08				·06	·08								·05			·29		·27	·48		1·59
Mauch Chunk,					·14		·02			·08									·34		·10			·09	·10		·12		·23	·95		2·17
Otisville,					·22					·04						·13					·15			·01		·03	·27		·22	·71		1·78
Philadelphia, a†					·03					·04	·02				·01	·11			·05		·05	·01		·03	·27	·04	·36		·32	·44		1·78
Philadelphia, b,					·03					·04	·01				·01	·13			·05		·05	·01		·01	·18	·02	·42		·40	·49		1·85
Philadelphia, c,					·02	·01				·03	·02	·01			·03	·14			·05		·08			·01	·33	·03	·38		·41	·50		2·11
Phœnixville,					·05		·01			·01	·09				·10	·01		·01	·08		·10	·01		·01	·09	·02	·32		·37	·55		1·83
Point Pleasant,					·04					·04	·02				·02	·03				·17	·04					·05	·32		·50	·61		1·84
Pottstown,					·10						·05				·20			·08			·11						·35		·90	·35		2·14
Quakertown,					·08					·07					·03	·12					·10			·02	·10		·25		·40	·70		1·87
Reading,					·04					·01	·01	·01			·01	·02			·02		·15	·01		·01	·10	·03	·16		·30	·73		1·61
Salem Corners,					·30		·09			·15	·05			·15		·40			·10			·11		·16	·15		·20		·30	·52	·10	2·78
Seisholtzville,					·09	·07									·20						·23	·02		·08		·04	·29		·46	·75		2·03
Skippack,																																
Smith's Corner,					·06					·05						·12			·10		·06			·02	·08	·05	·15		·53	·57		1·79
Swarthmore,																																
West Chester,					·03						·03				·05	·08			·05		·10			·11			·25		·34	·56		1·60
Westtown,					*	*	*	*	*	*	*	*	*	*	*				·15		·10			·14		·05				·95		1·39
Susquehanna Basin.																																
Altoona,					·06							·02									·12			·11	·08					·60		0·99
Aqueduct,					·20	·02				·03	·08				·08	·06					·25			·10		·02			·45	·26		1·55
Bloomsburg,					·32	·05				·05	·06				·15	·12			·06		·15			·21	·01	·05			·06	·60		1·89
Blue Knob,					·21	·01					·10	·05			·18	·19			·02		·04			·26			·05		·55	·80		2·46
Carlisle,					·20	·02				·05	·04	·01			·06	·02					·24			·07					·42	·66		1·79
Drifton,				·24	·23		*			·20	·05			*	·56				·05		*				·05	·05		*	·15	1·10		2·68
Emporium,				·09	·65	·05					·07				·17	·03		·02	·18		·73			·80					·76	·30		3·85
Gettysburg,					·03	·06						·04				·03	·11					·18			·07		·05		·06	·93		1·56
Girardville,	*				·13					·06	·04				·14	·10		·04			·08			·28		·15			·60	1·10		2·72
Grampian,					·52							·10			·20				·76					·50	·14	·07			·80	·06		3·15
Harrisburg,†					·27		·02				·10				·08	·04			·01		·20			·06		·02	·04		·53	·40		1·77
Hollidaysburg,					·09	·02									·15	·08			·05		·37			·28	*		·04		·19	·80		2·07
Huntingdon,					·12										·26	·04					·33			·21					·40	·56		1·82
Kilmer,					·24	·01									·10						·40			·09		·02			·66	·08		1·60
Lancaster,	*	*	*	*	*	*	*	*	*						·45						·20			·02		·05	·20		·20	·45		1·57
Lebanon,					·17					·02	·02	·01			·08	·09			·02		·12			·09	·06	·03	·10		·39	·97		2·17
Le Roy,					·42	·05					·05				·07	·15		·04			·24			·18	·13		·04		·26	·80		2·43
Lewisburg,					·53	·07				·02	·03				·23									·37		·01			·78	·80		2·84
Lock Haven,					·35	·08									·05	·22		·02			·30			·35					·15	·25		1·77
Selins Grove,											·01				·10						·35						·02		·25	·10		0·83
South Easton,					·15						·04			·04	·10	·10			·03		·04			·19		·03	·04		·13	·76		1·65
State College,					·17							·05				·04			·05		·41			·41					·20	·42		1·75
Wellsboro,				·10	·30	·05									·02	·10		·12			·10			·25					·21	1·00		2·25
Wilkes-Barre,					·21	·01			·23						·05	·07			·12		·08			·22			·05		·12	·47		1·63
Wysox,																																
York,					·13		·01			·02	·01				·03	·05			·02		·18			·08	·05	·02	·07		·40	·27		1·34

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Beaver Dam,					·44														·06			·05			·31					[illegible]		[illegible]
Brookville,	·04			·10	·41							·03	·02			·33			·13		·21				·75	·02				[illegible]	[illegible]	[illegible]
Clarion,				·01	·89	·04	·06					·09	·01		·01	·27			·29		·27	·25			·69					[illegible]	[illegible]	[illegible]
Columbus,																																
Confluence,					·20	·07	·05					·20				·24	·04		·20		·26	·29			·50					[illegible]		[illegible]
Davis Island Dam,					·25		·02					·01				·49	·03		·05		·28				·30					[illegible]		[illegible]
DuBois,				·05	·44	·05						·17				·21					·58				·98					[illegible]	·24	[illegible]
Elwood Junction,					·46							·01				·50	·01		·06		·22	·03			·43					·52		[illegible]
Freeport,					·48							·10				·45			·17		·48	·05			·65					[illegible]		[illegible]
Greensboro,					·10	·03					·05	·02			·05	·12	·02		·30		·20	·02			·60		[illegible]			[illegible]		[illegible]
Greenville,	*	*	*	*	*	*	*	*	*	*	*	*			·42			·24			·20			·26					[illegible]	[illegible]		[illegible]
Immel Reservoir,					·12						·04					·62			·25		·15			·43	·20		·05		[illegible]	[illegible]		[illegible]
Indiana,																																
Johnstown,	·01				·37	·02	·02				·03	·08				·32	·01		·28		·32	·03			·50		·06	[illegible]		[illegible]		[illegible]
Kane,	*	*		·24	·92	·04									·33	·04		·24			·40			1·10					[illegible]	[illegible]		[illegible]
Ligonier,	*	*	*	*	*	*	*	*	*															1·47				[illegible]	[illegible]			[illegible]
Lock No. 4,					·19						·04					·32			·17		·32				·59		[illegible]			[illegible]		[illegible]
Mahoning,					·37	·02						·05	·02			·35	·02		·21		·29	·08			·72					[illegible]	[illegible]	[illegible]
Meadville,					1·50								*		·38									·50					[illegible]			[illegible]
New Castle,					·39										·49			·07			·20			·24					[illegible]			[illegible]
Oil City,				·03	1·06	·01						·10				·32			·30		·40	·03			·62					[illegible]	[illegible]	[illegible]
Parker's Landing,	·01				·55	·01	·04					·08				·32			·20		·34	·12			·70					[illegible]	·04	[illegible]
Pittsburg,†					·23	·01					·02				·14	·34		·02	·05		·32			·29					·42	[illegible]		[illegible]
Ridgway,				·85							·05				·01				·17	·61	·05			·81					[illegible]	[illegible]	[illegible]	[illegible]
Saegerstown,				·34	·90	·04						·05	·05		·65									·04					[illegible]			[illegible]
Saltsburg,					·19		·01					·03				·46	·01		·12		·16	·06			·60					[illegible]	[illegible]	[illegible]
Shingle House,				·15	1·06	·02					·05	·05			·22	·05		·05	·19		·53			·92	·20				[illegible]	[illegible]		[illegible]
Smethport,					1·00											·25	·30				·55			·90					[illegible]	[illegible]		[illegible]
Somerset,				·45							·15				·25	·10		·15			·20			·22					1·25	·42		[illegible]
Stoyestown,				·10	·91						·10	·10				·26	·04	·12		·03	·31	·07			[illegible]	·21				[illegible]	·30	[illegible]
Uniontown,					·24						·41			·16		·06		·04	·19		·27			·46		·10			[illegible]	[illegible]		[illegible]
Warren,	·01			·09	·73	·01		·02				·10	·01		·03	·44	·04		·30		·06	·03			·44					[illegible]		[illegible]
West Newton,					·13	·08					·07					·34	·02		·26		·15	·14			·55					[illegible]		[illegible]
Potomac Basin.																																
Chambersburg,					·16											·16					·33			·06		·05			·15	[illegible]		[illegible]
McConnellsburg,																																
Lake Basin.																																
Erie,†				·10	·54	·01	·01					·01			·44	·06		·15	·01		·10			·08	·06		[illegible]	[illegible]	·39	[illegible]	[illegible]	[illegible]

† U. S. Weather Bureau Stations. * Missing

Snow.—Hamburg, 10th, 26th; Altoona, 12th, 21st, 25th, 30th; Blue Knob, 10th, 11th, 12th, 21st, 24th, 27th, 29th, 30th; Hollidaysburg, 24th; Le Roy, 11th, 25th, 27th, 29th, 30th; Quakertown, 10th, 18th, 26th, 27th, 29th, 30th; Johnstown, 10th, 11th, 12th, 21st, 25th, 26th, 29th, 30th; Emporium, 1st, 6th, 10th, 11th, 12th, 21st, 24th, 25th, 26th, 27th, 29th, 30th, 31st; East Mauch Chunk, 10th, 26th, 27th, 29th, 30th; State College, 10th, 11th, 12th, 21st, 24th, 29th, 30th; Coatesville, 26th, 27th, 30th; Phœnixville, 10th, 11th, 18th, 26th, 27th, 29th; Bloomsburg, 10th, 11th, 12th, 26th, 27th, 29th, 30th; Carlisle, 10th, 26th, 29th, 30th; Huntingdon, 29th, 30th; Kilmer, 11th, 21st, 26th, 29th, 30th; Lancaster, 26th, 27th, 30th; New Castle, 24th, 29th; Lebanon, 10th, 11th, 12th, 26th, 27th, 29th, 30th; Kane, 7th, 8th, 11th, 12th, 21st, 24th, 25th, 27th, 29th, 30th; Wilkes-Barre, 9th, 27th, 29th, 30th; Smethport, 21st, 24th, 29th, 30th; Easton, 10th, 11th, 18th, 26th, 30th; Aqueduct, 10th, 11th, 18th, 26th, 29th, 30th; *Philadelphia* [Centennial Avenue], 18th, 26th, 27th, 29th, 30th; [Locust Street], 10th, 11th, 18th, 26th, 27th, 30th; Selins Grove, 10th, 11th, 27th, 29th, 30th; Somerset, 24th, 29th, 30th; Wellsboro, 10th, 11th, 21st, 24th, 29th, 30th; Lewisburg, 9th, 10th, 26th, 30th; Dyberry, 6th, 10th, 11th, 12th, 14th, 18th, 21st, 25th, 26th, 27th, 29th, 30th; Honesdale, 10th, 14th, 27th, 29th, 30th; South Eaton, 12th, 14th, 27th, 29th, 30th; York, 10th, 11th, 18th, 26th, 27th, 30th.

Sleet.—Blue Knob, 21st, 24th; East Mauch Chunk, 29th; Lock Haven, 29th, 30th; Carlisle, 29th; Edinboro, 11th; Kilmer, 21st, 29th; Lebanon, 29th; Wilkes-Barre, 30th; Aqueduct, 29th; *Philadelphia* [Centennial Avenue], 11th, 26th, 29th, 30th; [Locust Street], 10th, 25th, 26th, 29th; Shingle House, 21st; Wellsboro, 29th; Salem Corners, 18th; South Eaton, 29th; York, 29th.

Aurora.—Hollidaysburg, 13th, 14th; Le Roy, 11th; Coatesville, 3d; Selins Grove, 3d; Wellsboro, 3d.

Solar Halo.—*Philadelphia* [Centennial Avenue], 3d.

Lunar Halo.—Hollidaysburg, 13th, 14th; Le Roy, 22d, 23d; Emporium, 17th, 20th; West Chester, 7th, 20th; Saegerstown, 17th; Carlisle, 14th, 18th, 19th, 23d, 25th; Uniontown, 15th; Lancaster, 4th, 22d; Wilkes-Barre, 13th; *Philadelphia*, Weather Bureau, 20th, 22d, 23d; [Centennial Avenue], 20th, 22d, 23d; Shingle House, 20th; Somerset, 21st; Honesdale, 20th, 22d.

Meteors.—Phœnixville, 20th.

MARCH WEATHER.

From United States Weather Bureau Records.

The following data, compiled from the records of observations taken during the length of time given at each station, show the average and extreme conditions during that time, and also the range within which weather variations may be expected to keep in any future March.

	Philadelphia. (22 years.)	Pittsburgh. (23 years.)	Erie. (20 years.)
Mean or normal, ...	39°	38°	32°
Warmest March, ... Average, ...	1871 49°	1871 47°	1878 43°
Coldest March, ... Average, ...	1885 31°	1872 31°	1885 25°
Highest temperature recorded, . . . Date, ...	75° 5th, 1880	80° 11th, 1876	78° 31st, 1875
Lowest temperature recorded, . . . Date, ...	5° 5th, 1872	2°, 4th, 1873 2°, 18th, 1877	Minus 7° 10th, 1877
Average date of last "killing" frost (spring), ...	April 9th	April 27th	April 30th
Average precipitation (inches), . . .	3·38	2·78	2·84
Average number of days with ·01 inch or more, ...	13	16	18
Greatest monthly precipitation, . . . Date, ...	6·71 1876	5·31 1877	5·41 1878
Least monthly precipitation, ... Date, ...	0·69 1885	1·03 1871	1·09 1874
Greatest amount in 24 hours, ... Date, ...	2·72 24th, 25th, 1876	1·39 6th, 1874	1·37 13th, 1878
Greatest amount snowfall in 24 hours, Date, ...	10·00 11th, 12th, 1888	3·50 19th, 1890	5·00 8th, 1886; 22d, 1888
Average number clear days, ... Partly cloudy, . . Cloudy, ...	8 11 12	5 13 13	6 11 14
Prevailing direction of wind, ...	NW.	NW.	W.
Highest velocity, miles per hour, . . Date, ...	60 12th, 1888	42 13th, 1891	55 1884

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU

T. F. TOWNSEND, WEATHER BUREAU, L. F. O. IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR FEBRUARY, 1894.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 28, 1894.

GENERAL REVIEW.

February's normal temperature and rainfall is about 30°·0 and 3·51 inches. The present month has been 2°·4 colder than the average, and the rainfall ·02 more.

The warmest days were the 8th, 9th, 10th, 18th, 19th and 28th, and the coldest on the 17th and 25th. The lowest temperatures recorded were Dyberry minus 24° and Honesdale minus 20°.

The snowfall was quite heavy for February and occurred on several days. The largest totals in inches were Salem Corners, 42·3; Somerset, 40·2; Blue Knob, 38·5, and Kilmer, 37·3. Nearly all stations report snow on ground at the end of the month.

A fine auroral display occurred on the 23d.

From January 1, 1894, to February 28, 1894, the excess in temperature at Philadelphia was 67°; Pittsburgh, 165°; and Erie, 120°.

For the same period the deficiency in precipitation at Philadelphia was 1·75; Erie, 1·31, and Pittsburgh, 0·96.

	Mean Temperature.	*Mean Precipitation Inches.*
February, 1888, ...	28°·4	2·50
1889, ...	23°·0	1·96
1890, ...	37°·1	4·32
1891, ...	34°·9	4·61
1892, ...	31°·7	1·75
1893, ...	27°·4	5·92
1894, ...	27°·6	3·53

NOTE.—Crop correspondents are requested to resume their reports the first week in April Blanks furnished on application.

TEMPERATURE.

The mean temperature for February, 1894, was 27°·6, which is 2°·4 below the normal, and 0°·2 above the corresponding month of 1893.

The means of the daily maximum and minimum temperatures, 36°·4 and 18°·9, give a monthly mean of 27°·6, with an average daily range of 17°·5.

Highest monthly mean, 36°·3 at Altoona.

Lowest monthly mean, 20°·2 at Dyberry.

Highest temperature recorded during the month, 64° on the 6th at Pittsburgh.

Lowest temperature, minus 24° on the 26th at Dyberry.

Greatest local monthly range, 73° at Dyberry.

Least local monthly range, 48° at Altoona and Harrisburg.

Greatest daily range, 56° at Ligonier.

BAROMETER.

The mean pressure for the month, 30·15, is about ·05 above the normal. At the United States Weather Bureau Stations, the highest observed was 30·86 at Philadelphia, on the 24th, and the lowest 29·46 at Erie on the 9th.

PRECIPITATION.

The average rainfall, 3·53 inches for the month, is an excess of 0·02.

The largest monthly totals in inches were Reading, 5·59; Somerset, 5·20; Kennett Square, 5·08; Blue Knob, 4·97, and Salem Corners, 4·90.

The least were Greenville, 1·62; New Castle, 1·76; Altoona, 1·82, and Grampian, 2·14.

WIND AND WEATHER.

The prevailing wind was from the Northwest.

Average number: rainy days, 11; clear days, 8; fair days, 9; cloudy days, 11.

MISCELLANEOUS PHENOMENA.

Thunder.—Quakertown, 19th; West Chester, 19th; Coatesville, 19th; Kennett Square, 19th, 25th; Phœnixville, 19th; Erie, 25th; Lancaster, 19th; Kane, 10th; Pottstown, 19th; Easton, 19th; *Philadelphia* [Weather Bureau], 19th; [Centennial Avenue], 19th; [Locust Street], 20th; York, 20th.

Hail.—Kennett Square, 25th; Phœnixville, 12th, 15th, 19th, 26th; Lebanon, 12th, 26th; Philadelphia [Centennial Avenue], 19th; Dyberry, 9th; York, 12th, 13th, 20th, 26th.

Snow.—Altoona, 1st, 3d, 4th, 9th, 12th, 13th, 15th, 18th, 26th, 27th; Blue Knob, 1st, 4th, 12th, 13th, 15th, 16th, 19th, 23d, 25th, 26th; Hollidaysburg, 1st, 4th, 12th, 13th, 15th, 25th, 26th; Quakertown, 1st, 4th, 10th, 14th, 15th, 16th, 22d, 25th, 26th; Johnstown, 1st, 4th, 12th, 13th, 14th, 15th, 16th, 25th, 26th; Emporium, 1st, 4th, 10th, 12th, 13th, 14th, 15th, 18th, 19th, 21st, 23d, 26th; East Mauch Chunk, 1st, 4th, 12th, 13th, 15th, 26th; State College, 1st, 4th, 12th, 13th, 15th, 26th; West Chester, 4th, 12th, 13th, 15th, 22d, 25th, 26th; Coatesville, 4th, 12th, 13th,

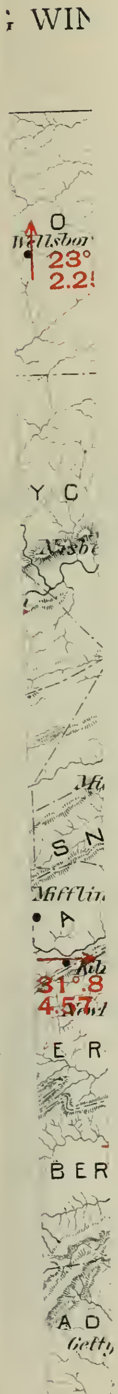
Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for February, 1894.

		Sea	Temperature.	Precipitation.	Number of Days.	m.

Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for February, 1894.

County.	Station.	Elevation above Sea Level (feet).	Temperature. Mean.	Maximum. Highest.	Maximum. Date.	Minimum. Lowest.	Minimum. Date.	Mean of Maximum.	Mean of Minimum.	Daily Range. Mean.	Daily Range. Greatest.	Precipitation. Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rain or Snow.	Number of Days. Clear.	Fair.	Cloudy.	Wind. Prevailing Direction.	Observers.
Allegheny,	Pittsburgh,	820	32·0	64	9	6	24	39·6	24·1	15·5	33	2·98	20·5	...	12	7	10	11	NW	O. D Stewart, W. B.
Berks,	Hamburg,	380	28·3	53	19	−3	17	35·6	21·0	14·6	37	4·47	29·5	12·0	8	3	16	9	E	William Shipe.
Berks,	Reading,[2]	280	28·0	...	...	...	...	...	...	...	...	5·59	...	...	14	...	...	...	...	Franklin Yager.
Blair,	Altoona,	1,181	36·3	58	20	10	25	45·5	27·1	18·4	24	1·82	...	...	10	...	...	...	...	Dr. C. B. Dudley.
Blair,	Blue Knob,	2,500	24·9	45	19, 28	−6	24	30·2	19·6	10·6	21	4·97	38·5	18·0	15	3	13	12	NW	A. H. Boyle.
Blair,	Hollidaysburg,	947	27·2	57	19	−9	17	38·5	15·9	22·6	51	4·23	26·0	5·0	13	13	5	10	W	Prof. J. A. Stewart.
Bradford,	Le Roy,	1,400	20·8	45	19	−16	25	27·8	13·7	14·1	36	3·04	24·7	8·0	13	10	8	10	SW	G. W. T. Warburton
Bucks,	Forks of Neshaminy[1] (27 days),	304	30·4	...	...	...	...	...	...	...		3·77	...	...	10	7	14	6	N	J. C. Hilsman.
Bucks,	Quakertown,	536	26·9	51	18	−7	17	36·0	17·8	18·2	47	4·16	16·5	10·0	9	4	15	9	NW	J. L. Heacock.
Cambria,	Johnstown,	1,184	29·8	54	28	1	17	38·4	21·1	17·3	48	3·32	23·0	1·0	20	4	10	14	NW	E. C. Lorentz.
Cameron,	Emporium,	1,050	25·6	53	28	−9	17	35·7	15·5	20·2	50	3·08	18·3	...	8	5	17	6	W	T. B. Lloyd.
Carbon,	E. Mauch Chunk,	550	26·0	53	18	−8	17	35·2	16·7	18·5	42	4·11	20·5	4·0	11	13	5	10	N	F. C. Wintermute
Centre,	State College—Agricultural Experiment Sta.,	1,191	26·4	51	19	−1	25	35·2	17·6	17·6	35	3·39	29·0	1·0	9	4	11	13	W	Prof. Wm. Frear.
Chester,	West Chester,	455	29·9	53	10, 18	2	25	37·2	22·6	14·6	28	4·66	18·0	3·0	13	12	2	14	W	J. C. Green, D.D.S.
Chester,	Coatesville,	380	30·6	59	10	2	25	40·4	20·8	19·6	36	4·60	22·9	6·0	12	11	6	11	W	W. T. Gordon.
Chester	Kennett Square,	275	30·7	57	18	3	25	40·2	21·2	19·0	43	5·08	19·0	3·0	12	6	6	16	NW	B. P. Kirk.
Chester,	Phœnixville,	190	30·0	56	18	4	25	38·0	22·1	15·9	33	3·99	23·5	6·0	14	7	4	17	NW	Knowles Croskey.
Chester,	Westtown (27 days),	350	29·1	52	10, 18	2	25	36·4	21·8	14·6	31	3·99	12·2	3·0	9	5	11	11	W	Harry Alger.
Clearfield,	Grampian,	1,450	23·8	50	28	−6	24, 17, 26	31·8	15·8	16·0	40	2·14	22·0	6·0	7	3	18	7	W	Nathan Moore.
Clinton,	Lock Haven,	560	27·8	55	8, 19	−6	17	39·0	16·6	22·4	46	3·67	34·0	1·0	8	10	6	12	W	Prof. J. A. Robb.
Columbia,	Bloomsburg,—State Normal School,	500	26·2	48	18, 19	−2	17	34·1	18·4	15·7	39	2·22	15·7	3·0	8	10	6	12	NW	Prof. J. G. Cope.
Crawford,	Meadville—Divinity Hall,	1,200	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Prf. J. H. Montgomery.
Crawford,	Saegerstown,	1,200	23·6	50	9, 10	−14	5	31·9	12·2	22·7	43	2·70	12·5	..	7	6	8	14	NW	J. G. Apple.
Cumberland,	Carlisle,	480	28·9	56	18	−2	17	37·0	20·8	16·2	42	4·53	22·0	8·0	11	12	4	12	W	J. E. Pague.
Cumberland,	Carlisle—Dickinson College,	480	...	...	...	...	...	...	...	...	...	...		...	...	...	...		.	Prof. C. F. Himes.
Dauphin,	Harrisburg,	361	29·0	51	18	3	25	34·7	22·5	12·2	26	4·56	23·5	..	13	6	8	14	E	F. Ridgway, W. B.
Delaware,	Swarthmore—Swarthmore College,	190	32·2	55	10	5	25	39·1	25·3	13·8	30	3·17	16·2	6·0	11	3	16	9	N	Prof. S. J. Cunningham.
Erie,	Edinboro,*[1]	1,400	21·6	40	8	2	24	...	...	...	...	.	18·0	2·0	...	16	6	6	E	C. F. Sweet.
Erie,	Erie,	681	25·0	50	9	−2	25	32·0	19·0	13·0	32	3·55	...	.	14	7	6	15	S	P Wood, W. B.
Fayette,	Uniontown,	1,000	33·6	62	9	9	24	41·1	26·0	15·1	40	3·35	15·0	...	11	8	13	7	NW	Wm. Hunt.
Franklin,	Chambersburg,	618	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	David Rhea.
Fulton,	McConnellsburg,	875	...	...	...	...		...	...	...	...	...	...	...	...	...	...	...	...	T. F. Sloan.
Huntingdon,	Huntingdon—The Normal College,	650	29·0	57	19	−6	17	39·2	18·8	20·4	49	3·44	25·3	3·0	8	11	6	11	W	Prof. W. J. Swigart.
Indiana,	Indiana—State Normal School,	1,350	...	...	...	...	...	..	...	..	...	...	...	...	..	...	...	..	...	Prof. S C. Schmucker.
Juniata,	Kilmer,*[1]	475	31·8	54	10	2	17	...	...	...	..	4·57	37·3	8·0	9	10	8	10	W	R. J. Mickey.
Lancaster,	Lancaster—Franklin and Marshall Col'ge,	413	29·9	53	10	1	17	38·0	21·8	16·2	41	3·50	22·8	7·0	7	12	5	11	E	W. E. Bushong.
Lawrence,	New Castle,	932	27·4	54	9, 28	−3	2	36·8	17·9	18·9	35	1·76	11·0	..	9	9	2	17	W	Wm. T. Butz.
Lebanon,	Lebanon,	458	28·4	53	18	−1	17	36·8	19·9	16·9	40	4·23	25·2	4·0	12	9	6	13	NW	G. W. Hayes, C.E.
Lehigh,	Coopersburg,	520	28·6	54	8	1	25	37·1	20·0	17·1	38	4·26	17·7	9·0	11	11	9	8	NW	Dr. M. H. Boye.
Luzerne,	Drifton (23 days),	1,683	27·8	54	8	−10	26	44·8	10·9	33·9	50	3·40	34·0	11·0	11	6	8	9	N	J. R. Wagner.
Luzerne,	Wilkes-Barre,	575	28·4	56	19	−1	17, 25	38·8	18·1	20·7	40	4·50	25·0	...	9	14	3	11	NW	A. W. Betterly.
McKean,	Kane,	2,000	23·0	48	28	−8	24	32·0	14·0	18·0	36	2·30	14·7	6·0	7	8	8	12	SE	C. H. Kemp.
McKean,	Smethport,	1,500	22·8	51	28	−15	25	32·3	13·2	19·1	52	3·35	15·5	...	9	...	...	..	NW	Armstrong & Brownell.
Mercer,	Greenville—Thiel College,	1,000	25·7	57	9	−2	25	35·0	16·4	18·6	34	1·62	10·5	...	7	9	5	14	NW	Prof. S. H. Miller.
Montgomery,	Pottstown,	150	29·9	54	18	3	17, 25	37·0	22·8	14·2	36	4·25	19·5	3·0	11	12	5	11	NE	Charles Moore, D.D.S.
Montgomery,	Skippack,	...	...	...	...	...	...	...	...	...	...	...	...	...	...	.	...	..	...	B. W. Dambly.
Northampton,	Easton—Lafayette College,	325	26·6	51	8	−2	17	34·8	18·4	16·4	36	3·39	18·6	...	9	10	6	12	...	J. W. Moore.
Perry,	(Aqueduct) Logania,	367	30·6	56	18	0	17	38·8	22·5	16·3	43	4·69	27·4	7·5	15	10	9	9	NW	Richard Callin.
Philadelphia,	U. S. Weather Bureau,	117	32·0	56	8	4	25	38·5	25·3	13·2	26	3·07	11·5	...	12	5	11	12	NE	L. M. Dey, W. B.
Philadelphia,	1529 Centennial Avenue,	120	32·4	57	18	3	25	39·5	25·4	14·1	24	4·33	12·9	3·0	13	7	9	12	NE	John Comly.
Philadelphia,	3911 Locust Street,	100	31·6	55	18	4	25	38·2	25·1	13·1	24	4·74	12·3	2·0	14	9	8	11	NE	R. I. Paddock
Pike,	Blooming Grove,*[1]	...	23·4	47	18	−16	25	...	...	...	...	3·40	31·0	10·0	6	6	10	12	W	John Grathwohl.
Potter,	Shingle House,	1,475	21·6	51	28	−18	25	32·5	10·8	21·7	51	3·02	21·0	6·0	11	6	8	14	W	C. D. Voorhees, M.D.
Schuylkill,	Girardville,[1]	1,000	.	...	...	...	...	...	...	...	...	.	...	...	...	...	...	...	...	E. C. Wagner.
Snyder,	Selins Grove,	455	29·0	52	18	−6	17	38·1	20·0	18·1	40	3·87	28·5	10·0	9	..	22	6	NW	J. M. Boyer,
Somerset,	Somerset,	2,250	26·2	56	9	0	24, 17, 26	34·0	18·5	15·5	41	5·20	40·2	3·0	11	1	13	14	NW	W. M. Schrock.
Tioga,	Wellsboro,*[1]	1,327	23·4	56	19	−16	25	.	...	...	...	2·25	19·0	10·5	8	9	8	11	S	H. D. Deming
Union,	Lewisburg,	450	26·2	51	19	−16	17	36·4	16·0	20·4	52	2·46	22·5	4·0	8	13	8	7	W	Prof. W. G. Owens.
Wayne,	Dyberry,	1,100	20·2	49	18, 19	−24	25	31·8	8·5	23·3	49	2·73	30·0	20·0	11	6	12	10	NW	Theodore Day.
Wayne,	Honesdale,	1,000	22·8	49	18	−20	25	34·0	11·5	22·5	48	3·63	32·0	24·0	11	11	9	8	...	John Torrey
Wayne,	(Salem Corners) Hamlinton,	1,600	22·5	57	19	−10	25	30·2	14·8	15·4	34	4·90	42·3	30·0	13	6	9	13	W	T. B. Orchard, M. D.
Westmoreland,	(Immel Reservoir) Lycippus,	1,420	29·4	60	19	5	5	36·5	22·2	14·3	31	2·31	19·0	...	8	...	...	...	...	Murray Forbes
Westmoreland,	Ligonier,	1,750	29·5	58	10	−4	17	40·2	18·8	21·4	56	2·78	26·0	1·0	11	11	7	10	...	C. D. Ambrose.
Wyoming,	South Eaton,	660	24·8	58	27	−9	17, 25	34·4	15·1	19·3	54	2·79	16·0	3·0	10	8	9	11	NW	B. M. Hall.
York,	York,	385	29·6	54	10	−2	17	38·2	21·0	17·2	44	4·20	25·2	5·0	11	9	11	8	NW	Mrs. L. H. Greenewald.

Mean temperature from maximum and minimum readings. *Extremes from dry thermometers. [1] Mean temperatures, 7 + 2 + 9 + 9 ÷ 4. [2] Mean temperature 8 + 8 ÷ 2.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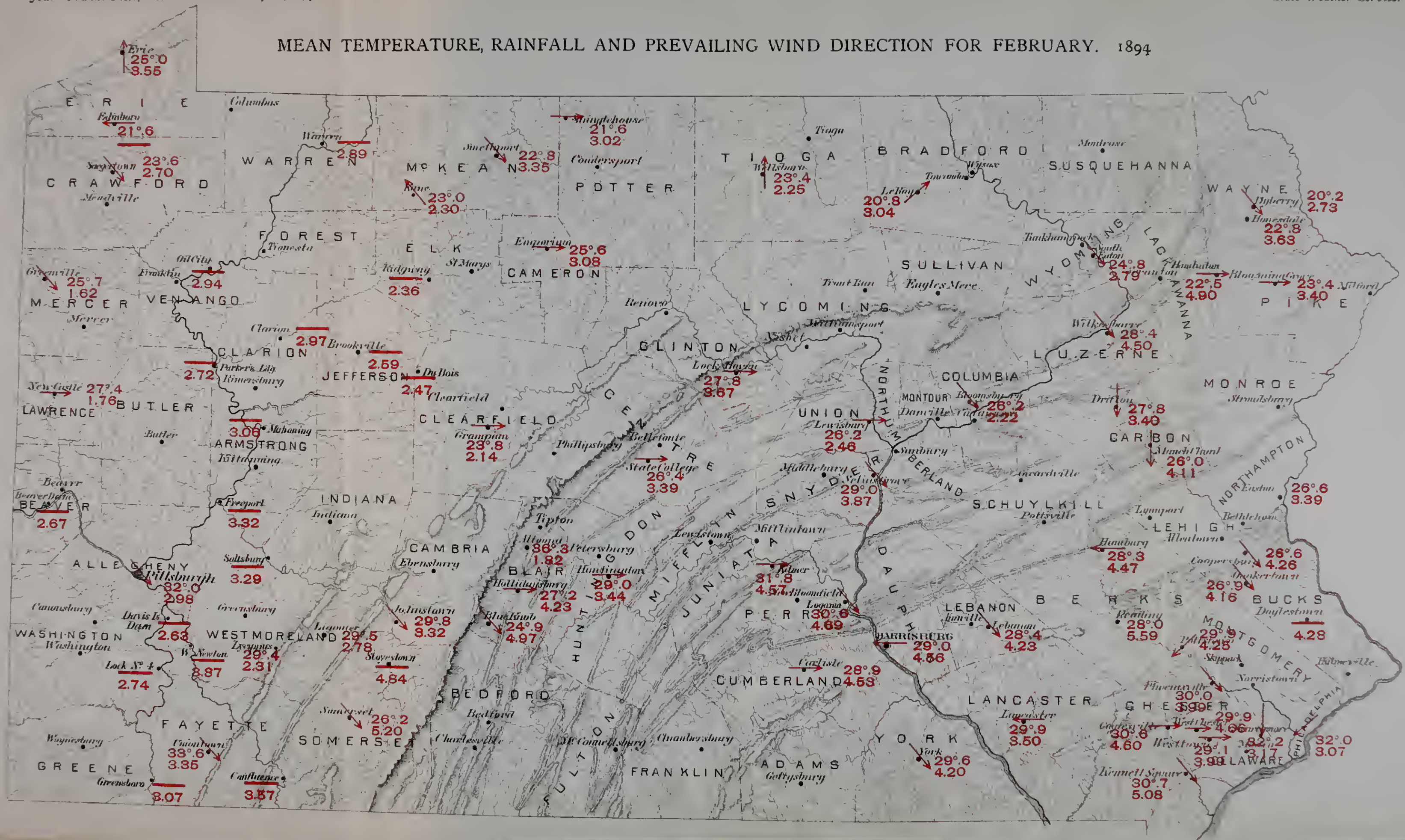
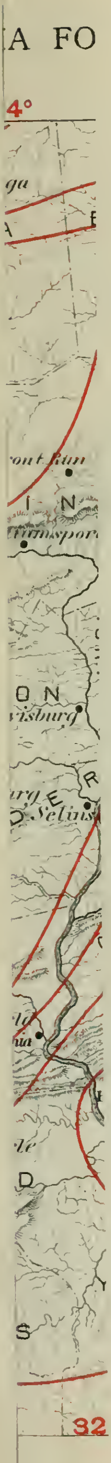
MEAN TEMPERATURE, RAINFALL AND PREVAILING WIND DIRECTION FOR FEBRUARY. 1894

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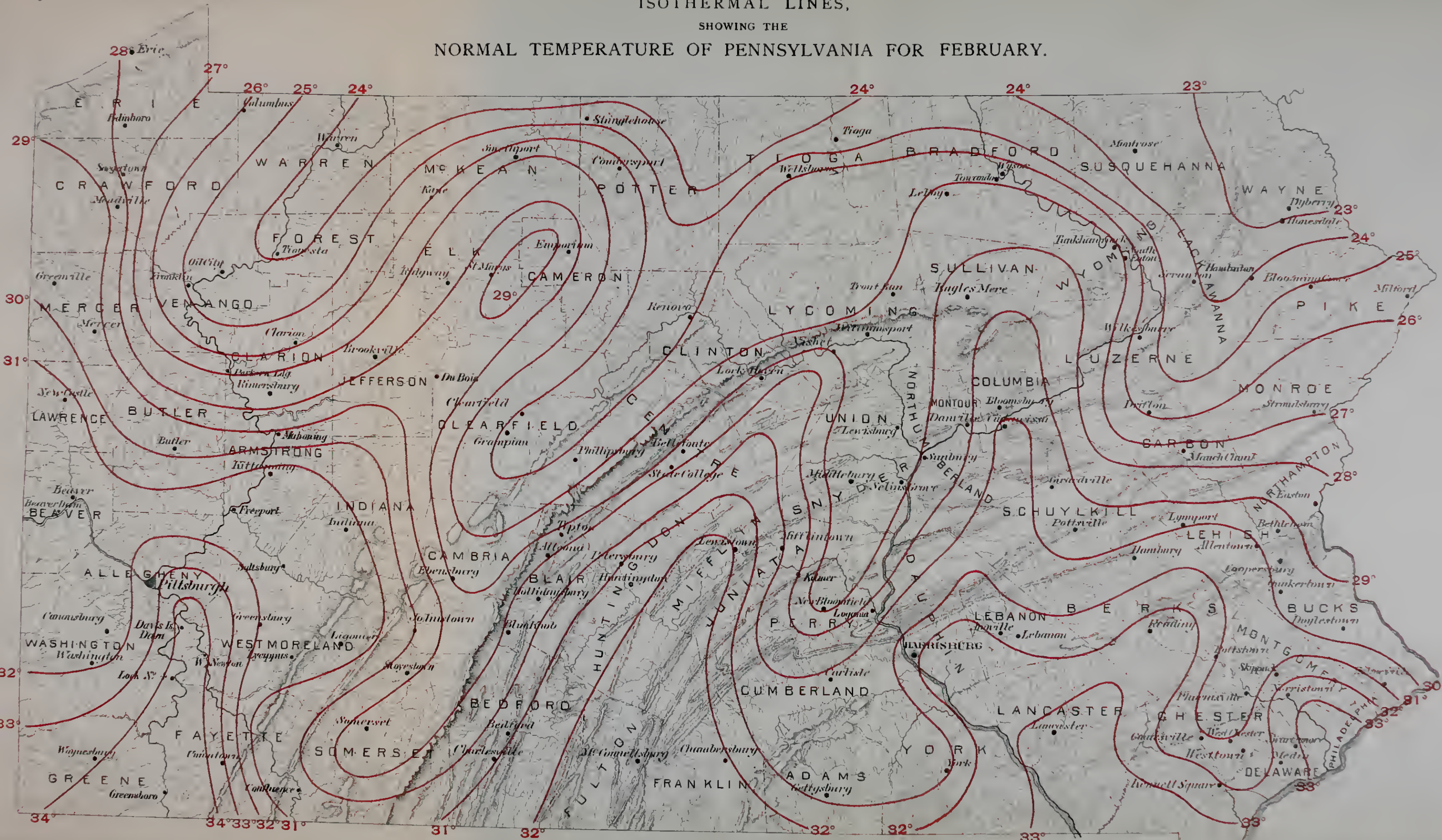
ISOTHERMAL LINES,
SHOWING THE
NORMAL TEMPERATURE OF PENNSYLVANIA FOR FEBRUARY.



14th, 15th, 22d, 25th, 26th; Phœnixville, 1st, 12th, 13th, 14th, 15th, 25th, 26th; Westtown, 1st, 4th, 12th, 13th, 22d, 25th, 26th; Grampian, 1st, 3d, 9th. 13th, 15th, 26th; Lock Haven, 1st, 4th, 12th, 13th, 15th, 26th; Bloomsburg, 1st, 4th, 12th, 13th, 14th, 15th, 26th; Carlisle, 1st, 4th, 12th, 13th, 14th, 15th, 26th; Swarthmore, 4th, 13th, 22d, 25th, 26th; Huntingdon, 1st, 4th, 12th, 13th, 15th, 26th; Kilmer, 1st, 4th, 12th, 13th, 26th; Lancaster, 4th, 12th, 13th, 15th, 26th; Lebanon, 1st, 3d, 4th, 12th, 13th, 14th, 15th, 19th, 25th, 26th; Coopersburg, 1st, 4th, 12th, 13th, 14th, 15th, 25th, 26th; Drifton, 1st, 2d, 4th, 10th, 12th, 15th, 16th, 19th, 20th, 24th, 27th; Wilkes-Barre, 1st, 4th, 13th, 15th, 26th; Kane, 1st, 12th, 13th, 15th, 23d; Smethport, 1st, 4th, 12th, 13th, 15th; Greenville, 1st, 4th, 12th, 13th, 15th, 26th; Pottstown, 1st, 4th, 12th, 14th, 21st, 25th, 26th; Easton, 1st, 4th, 14th, 15th, 16th, 26th; Logania, 1st, 4th, 12th, 13th, 14th, 15th, 25th, 26th; *Philadelphia* [Centennial Avenue], 1st, 4th, 12th, 13th, 15th, 22d, 25th, 26th; [Locust Street], 1st, 4th, 12th, 13th, 15th, 22d, 25th, 26th; Blooming Grove, 2d, 10th, 13th, 16th, 19th, 26th; Shingle House, 1st, 4th, 9th, 10th, 12th, 13th, 15th, 16th, 23d; Selins Grove, 4th 12th, 13th, 15th, 26th; Somerset, 1st, 3d, 4th, 5th, 12th, 13th, 15th, 16th, 26th; Wellsboro, 1st, 4th, 9th, 12th, 13th, 15th; Lewisburg, 1st, 3d, 12th, 13th, 15th, 26th; Dyberry, 1st, 4th, 9th, 12th, 13th, 14th, 15th, 16th, 20th, 26th; Honesdale, 1st, 4th, 9th, 12th, 13th, 15th, 20th, 26th; Salem Corners, 1st, 4th, 5th, 9th, 12th, 13th, 14th, 15th, 20th, 26th, 27th; Immel Reservoir, 5th, 12th, 16th, 26th; Ligonier, 1st, 4th, 13th, 14th, 15th, 26th; York, 4th, 12th, 13th, 15th, 22d, 25th, 26th.

Sleet.—Kennett Square, 15th; Phœnixville, 15th; Westtown, 12th, 15th, 26th; Lock Haven, 7th; Lebanon, 19th, 26th; Coopersburg, 12th, 26th; Logania, 3d, 12th, 19th, 26th; Philadelphia [Centennial Avenue], 12th, 13th, 19th; Somerset, 12th, 26th; Dyberry, 9th; York, 26th.

Aurora.—Hollidaysburg, 24th; Emporium, 23d; Mauch Chunk, 23d; State College, 22d, 23d; West Chester, 23d; Coatesville, 23d; Kennett Square, 23d; Phœnixville, 23d; Westtown, 23d; Lock Haven, 23d, 24th; Harrisburg, 23d; Swarthmore, 16th; Coopersburg, 23d; Wilkes-Barre, 22d; Philadelphia, 23d; [Centennial Avenue], 23d; Shingle House, 21st, 28th; Selins Grove, 23d; Somerset, 22d; Wellsboro, 23d; Lewisburg, 15th, 18th, 20th; Dyberry, 23d; York, 23d.

Coronæ.—Saegerstown, 16th; Salem Corners, 18th, 20th.

Solar Halo.—Le Roy, 5th, 8th, 20th, 25th 28th; *Philadelphia* [Weather Bureau], 17th, 24th, 25th; [Centennial Avenue], 24th, 25th; [Locust Street], 17th, 24th; Wellsboro, 17th, 19th, 28th.

Lunar Halo.—State College, 17th, 18th; Uniontown, 15th, 17th; Lancaster, 20th; *Philadelphia* [Weather Bureau], 15th, 18th; [Centennial Avenue], 15th, 18th; [Locust Street], 15th, 18th.

APRIL WEATHER.

From United States Weather Bureau Records.

The following data, compiled from the records of observations taken during the length of time given at each station, show the average and extreme conditions during that time, and also the range within which weather variations may be expected to keep in any future April.

	Philadelphia. (22 years.)	Pittsburgh. (23 years.)	Erie. (20 years.)
Mean or normal,	51°	51°	44°
Warmest April, Average,	1871 57°	1878 57°	1878 54°
Coldest April, Average,	1874 42°	1874 42°	1874 37°
Highest temperature recorded, Date,	91° 30th, 1888	89° 23d, 1885	86° 14th, 1883
Lowest temperature recorded, Date,	18° 12th, 1874	14° 13th, 1875	11° 5th, 1881
Average date of last "killing" frost (spring),	April 9th	April 27th	April 30th
Average precipitation (inches),	2·87	2·70	2·56
Average number of days with ·01 inch or more,	11	14	13
Greatest monthly precipitation, Date,	9·76 1874	7·20 1874	3·86 1880
Least monthly precipitation, Date,	0·61 1881	1·04 1888	1·14 1892
Greatest amount in 24 hours, Date,	1·67 3d, 1876	2·56 28th and 29th, 1887	1·81 6th, 1886
Greatest amount snowfall in 24 hours, Date,	1·00 4th, 1886	4·50 6th, 1889	7·00 15th, 1893
Average number clear days, Partly cloudy, Cloudy,	9 11 10	8 12 10	8 12 10
Prevailing direction of wind,	NW	NW	W
Highest velocity, miles per hour, Date,	50 3d, 1879	36 7th, 1893	60 1875

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

T. F. TOWNSEND, WEATHER BUREAU, L. F. O. IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR MARCH, 1894.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 31, 1894.

GENERAL REVIEW.

March's normal temperature and rainfall is about 35°·0 and 3·57 inches. The present month has been 8°·2 warmer than the average, and the rainfall 1·94 less.

The warmest days were the 6th, 18th and 22d, and the coldest 1st, 26th, 27th and 28th. The lowest temperature recorded was Saegerstown, minus 2° on the 28th.

There was a deficiency of 1·94 of precipitation. The rainfall was quite evenly distributed and occurred at short intervals. The snowfall was light, and only one station reported any on ground at end of month.

A brilliant auroral display occurred on the 30th.

This issue completes the publication of the series of charts showing by isothermal lines the normal temperature of each month of the year.

From January 1, 1894, to March 31, 1894, the excess in temperature at Philadelphia was 315°; Pittsburgh, 416°; and Erie, 357°.

For the same period the deficiency in precipitation at Philadelphia was 3·45; Erie, 2·31; and Pittsburgh, 1·40.

TEMPERATURE.

	Mean Temperature.	Mean Precipitation, Inches.
March, 1888,	31°·1	3·55
1889,	38°·9	2·90
1890,	33°·4	5·15
1891,	34°·1	5·10
1892,	32°·0	4·14
1893,	34°·7	2·52
1894,	43°·2	1·63

The means of the daily maximum and minimum temperatures, 53°·8 and 32°·5, give a monthly mean of 43°·2, which is about 8°·2 above the normal, and 8°·5 above the corresponding month of 1893.

The average daily range was 21°·3.

Highest monthly mean, 49°·4 at Altoona.

Lowest monthly mean, 37°·5 at Honesdale.

Highest temperature recorded during the month, 84° on the 22d at Logania.

Lowest temperature, minus 2° on the 28th at Saegerstown.

Greatest local monthly range, 77° at Saegerstown.

Least local monthly range, 50° at Altoona.

Greatest daily range, 48° at Ligonier.

BAROMETER.

The mean pressure for the month, 30·10, is about ·08 above the normal. At the United States Weather Bureau Stations, the highest observed was 30·62 at Philadelphia on the 28th, and the lowest 29·63 at Philadelphia and Harrisburg on the 13th.

PRECIPITATION.

The average rainfall, 1·63 inches for the month, is a deficiency of 1·94.

The largest monthly totals in inches were Uniontown, 2·90; Davis Island Dam, 2·64; Mahoning, 2·55; Blue Knob, 2·49, and Pittsburgh, 2·41.

The least were Wellsboro, 0·24; Altoona, 0·80; South Eaton, 0·80; Lock Haven, 0·84; Le Roy, 1·00, and Kilmer, 1·03.

WIND AND WEATHER.

The prevailing wind was from the West.

Average number: rainy days, 8; clear days, 12; fair days, 11; cloudy days, 8.

MISCELLANEOUS PHENOMENA.

Thunder.—Blue Knob, 13th, 15th, 23d, 31st; Hollidaysburg, 15th, 22d; Quakertown, 13th, 22d; Johnstown, 1st, 2d; Emporium, 15th; State College, 15th; West Chester, 23d; Kennett Square, 23d; Phœnixville, 22d; Westtown, 22d; Bloomsburg, 13th; Saegerstown, 15th; Carlisle, 22d; Harrisburg, 15th, 26th; Swarthmore, 6th, 23d; Uniontown, 15th, 22d; Hunting-

Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for March, 1894.

		ove Sea	Temperature.						Precipitation.				Number of Days.			nd. Direction.	Observers.
				Maximum.	Minimum.			Daily Range.		fall onth.	Snow d at onth.	Days now.					

Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for March, 1894.

County.	Station.	Elevation above Sea Level (feet).	Temperature.									Precipitation.				Number of Days.			Wind.	Observers.
			Mean.	Maximum. Highest.	Maximum. Date.	Minimum. Lowest.	Minimum. Date.	Mean of Maximum.	Mean of Minimum.	Daily Range. Mean.	Daily Range. Greatest.	Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rain or Snow.	Clear.	Fair.	Cloudy.	Prevailing Direction.	
Allegheny,	Pittsburgh,	820	47.0	76	18, 20	15	27	57.9	37.0	20.9	38	2.41	3.1	.	9	14	9	8	NW	O. D. Stewart, W. B.
Berks,	Hamburg,	380	43.4	75	22	15	28	53.8	33.1	20.7	36	1.53	...	...	6	5	15	11	NW	William Shipe.
Berks,	Reading,[2]	280	42.0	...		...	...	...	...	...	...	1.32	...	...	9	...	...	...	...	Franklin Yager.
Blair,	Altoona,	1,181	49.4	73	22, 23	23	26, 30	58.5	40.2	18.3	27	.80	...	...	5	...	...	...	...	Dr. C. B. Dudley.
Blair,	Blue Knob,	2,500	40.8	65	22	11	28	48.9	32.8	16.1	30	2.49	2.5	.	7	7	11	13	NW	A. H. Boyle.
Blair,	Hollidaysburg (29 days),	947	43.5	75	22	13	26, 27, 28	57.0	30.0	27.0	45	1.44	0.5	...	7	12	8	9	W	Prof. J. A. Stewart.
Bradford,	Le Roy,	1,400	38.0	64	18	10	27	46.6	29.5	17.1	26	1.00	2.3	...	8	9	10	12	SW	G. W. T. Warburton
Bucks,	Forks of Neshaminy[1] (27 days),	304	44.2		...	...			...	...	...	1.70	...	...	11	12	8	7	W	J. C. Hilsman.
Bucks,	Quakertown,	536	42.4	73	22	16	26	53.6	31.2	22.4	34	1.68	...	...	9	3	23	5	SW	J. L. Heacock.
Cambria,	Johnstown,	1,184	44.4	74	18	15	27, 28	56.5	32.4	24.1	43	1.95	1.0	...	9	8	14	9	NW	E. C. Lorentz.
Cameron,	Emporium,	1,050	40.8	73	18	11	28	53.5	28.2	25.3	44	1.24	3.2	...	8	8	16	7	SW	T. B. Lloyd.
Carbon,	E. Mauch Chunk,	550	41.6	69	22	14	28	52.8	30.5	22.3	39	1.67	1.0	...	10	17	5	9	W	F. C. Wintermute.
Centre,	State College—																			
	Agricultural Experiment Sta.,	1,191	42.7	69	22	13	27	52.8	32.6	20.2	33	1.14	2.0	...	7	6	15	10	W	Prof. Wm. Frear.
Chester,	West Chester,	455	45.1	77	22	18	27	54.4	35.8	18.6	29	1.67	...	...	10	21	3	7	S	J. C. Green, D.D.S.
Chester,	Coatesville,	380	44.8	80	22	17	28	56.9	32.6	24.3	39	2.08	...	...	8	19	5	7	W	W. T. Gordon.
Chester	Kennett Square,	275	45.4	80	22	17	28	56.7	34.0	22.7	37	1.45	.	...	12	15	8	8	NW	B. P. Kirk.
Chester,	Phœnixville,	190	45.3	78	22	16	27	55.5	35.1	20.4	36	1.76	.	...	11	10	11	10	NW	Knowles Croskey.
Chester,	Westtown,	350	43.7	77	22	18	27	53.2	34.2	19.0	35	1.60	...		10	12	9	10	W	John D. Carter.
Clearfield,	Grampian,	1,450	40.4	70	6, 18	10	27	50.0	30.8	19.2	36	2.27	3.0	...	7	5	17	9	W	Nathan Moore.
Clinton,	Lock Haven,	560	42.5	74	6, 18	13	28	56.3	28.7	27.6	44	.84	...	...	6	13	12	6	W	Prof. J. A. Robb.
Columbia,	Bloomsburg,—(27 days)																			
	State Normal School,	500	42.7	67	26	17	27	53.2	32.2	21.0	46	.31	1.5	...	3	13	7	7	NW	Prof. J. G. Cope.
Crawford,	Meadville—																			
	Divinity Hall,	1,200	...	...	...	...	...	...	...	...		.	...	...	...	...	...	...	...	Prf. J. H. Montgomery
Crawford,	Saegerstown,	1,200	41.0	75	18	— 2	28	53.8	28.3	25.5	45	1.74	3.0	...	7	4	16	11	S	J. G. Apple.
Cumberland,	Carlisle,	480	43.2	78	22	15	1	54.4	32.1	22.3	36	1.14	...	...	7	20	7	4	S	J. E. Pague.
Cumberland,	Carlisle—																			
	Dickinson College,	480	43.6	76	22	15	1	54.5	32.6	21.9	37	.48	.	...	2	16	7	8	W	H. E. Smith.
Dauphin,	Harrisburg,	361	44.0	75	22	19	27	53.0	36.0	17.0	30	1.30	...		8	13	9	9	W	F. Ridgway, W. B.
Delaware,	Swarthmore—																			
	Swarthmore College,	190	46.1	78	22	18	27	55.3	36.9	18.4	31	1.34	...	...	7	3	24	4	SW	Prof. S. J. Cunningham.
Erie,	Edinboro,*[1]	1,400	39.7	68	18	13	27	...	...	...	...	.	10.0	2.0	...	17	7	7	S	C. F. Sweet.
Erie,	Erie,	681	41.0	75	18	17	26	49.0	33.0	16.0	36	1.95	...		14	8	16	7	S	P. Wood, W. B.
Fayette,	Uniontown,	1,000	45.8	76	20	16	27	56.0	35.5	20.5	37	2.90	2.0	...	10	12	16	3	SW	Wm. Hunt.
Franklin,	Chambersburg (30 days),	618	43.2	74	22	15	1	55.4	30.9	24.5	37	1.17	...	...	7	10	13	7	NW	J. C. Boggs.
Fulton,	McConnellsburg,	875	...	...	...	...		...	...	...	...	...			...	...	...	...	...	T. F. Sloan.
Huntingdon,	Huntingdon—																			
	The Normal College,	650	44.0	75	22	14	28	57.8	30.1	27.7	44	1.07	...	...	5	16	5	10	W	Prof. W. J. Swigart.
Indiana,	Indiana—																			
	State Normal School,	1,350	...	...	...	...	...		...	...	...	...	...	...	...	...	...	...	...	Prof. S. C. Schmucker.
Juniata,	Kilmer,*[2]	475	46.1	70	19	20	1	...	...	...	...	1.03	...	...	4	10	14	7	W	R. J. Mickey.
Lancaster,	Lancaster—																			
	Franklin and Marshall Col'ge,	413	44.8	78	22	17	1	55.7	33.8	21.9	35	1.49		...	5	15	10	6	W	W. E. Bushong.
Lawrence,	New Castle,	932	42.8	75	18	13	27	55.2	30.4	24.8	45	1.47	1.2	...	5	11	11	0	W	Wm. T. Butz.
Lebanon,	Lebanon,	458	43.6	76	22	17	28	53.7	33.4	20.3	34	1.48	...	...	9	15	8	8	W	G. W. Hayes, C.E.
Lehigh,	Coopersburg,	520	43.8	72	22	18	27	53.6	33.9	19.7	33	1.60	...	...	11	14	10	7	SE	Dr. M. H. Boye.
Luzerne,	Drifton,	1,683	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	J. R. Wagner.
Luzerne,	Wilkes-Barre,	575	43.8	70	6	16	27	55.6	32.0	23.6	40	1.68	2.0	...	8	13	9	9	W	A. W. Betterly.
McKean,	Kane,	2,000	39.6	72	18	9	27	49.8	29.4	20.4	32	2.24	6.0	...	9	11	8	12	SE	C. H. Kemp.
McKean,	Smethport,	1,500	39.0	75	18	7	28	50.8	27.2	23.6	46	1.86	5.0		8	...	20	11	SE	Armstrong & Brownell.
Mercer,	Greenville—																			
	Thiel College,	1,000	43.0	77	18	12	27	54.4	31.5	22.9	43	1.94	2.0		8	19	2	10	S	Prof. S. H. Miller.
Montgomery,	Pottstown,	150	45.4	80	22	20	1, 27	55.7	35.1	20.6	35	1.74	...		8	21	3	7	W	Charles Moore, D.D.S
Montgomery,	Skippack,	...	...	...	...	...	...	...	...	...	...	...	...	...	...		...	...	...	B. W. Dambly.
Northampton,	Easton—																			
	Lafayette College,	325	42.4	69	22	16	27	51.3	33.6	17.7	31	1.25	...	...	9	11	11	9	...	J. W. Moore.
Perry,	(Aqueduct) Logania,	367	46.0	84	22	15	27, 28	56.0	35.9	20.1	35	1.09	...	...	7	18	5	8	NW	Richard Callin.
Philadelphia,	U. S. Weather Bureau,	117	47.0	77	22	21	27	55.8	38.3	17.5	29	1.45	...	...	10	12	8	11	NW	L. M. Dey, W. B
Philadelphia,	1529 Centennial Avenue,	120	47.3	80	22	21	27	56.4	38.2	18.2	31	1.64	...	...	11	12	11	8	NW	John Comly.
Philadelphia,	3911 Locust Street,	100	45.9	77	22	21	27	54.6	37.2	17.4	30	1.70		...	13	13	11	7	NE	R. L. Paddock.
Pike,	Blooming Grove,*[1]	...	39.6	67	18	17	27	...	...	...	...	1.11	.	...	5	5	16	10	S	John Grathwohl.
Potter,	Shingle House,	1,475	38.8	72	18	11	27, 28	50.8	26.8	24.0	43	1.84	6.2	...	9	6	15	10	NW	C. D. Voorhees, M.D.
Schuylkill,	Girardville,	1,000			...	...	...	...	...	...	...	.	.		...	...	...	...	...	E. C. Wagner.
Snyder,	Selins Grove,	455	42.6	74	22	16	27	54.5	30.8	23.7	37	1.09	.	...	2	29	...	2	SW	J. M. Boyer,
Somerset,	Somerset,	2,250	43.6	74	18	8	27	54.1	33.2	20.9	36	1.85	3.5		7	5	18	8	SW	W. M. Schrock.
Tioga,	Wellsboro,*[1]	1,327	36.3	72	18	10	27	.	...	...	...	.24	2.0	...	2	7	12	12	S	H. D. Deming
Union,	Lewisburg,	450	42.5	68	22	16	27	54.2	30.8	23.4	36	1.13	1.5		6	9	5	17	W	Prof. W. G. Owens.
Wayne,	Dyberry,	1,100	37.7	66	18	11	27	49.0	26.4	22.6	43	1.55	2.5		6	10	8	13	W	Theodore Day.
Wayne,	Honesdale,	1,000	37.5	64	19	12	27	47.4	27.6	19.8	34	1.59	1.2	...	10	13	8	10	NW	John Torrey †
Wayne,	(Salem Corners) Hamlinton,	1,600	39.6	66	5, 19	14	26	48.2	31.0	17.2	30	1.73	2.5	...	11	13	5	13	W	T. B. Orchard, M. D.
Westmoreland,	(Immel Reservoir) Lycippus,	1,420	45.0	77	21	11	27	53.0	37.1	15.9	30	2.31	...					...		Murray Forbes
Westmoreland,	Ligonier,	1,750	42.8	78	18	4	27	56.9	28.8	28.1	48	2.29	2.0		8	14	10	7	...	C. D. Ambrose.
Wyoming,	South Eaton,	660	41.2	67	6, 19	14	27	51.4	31.0	20.4	36	.80	...	...	7	10	12	9	NW	B. M. Hall.
York,	York,	385	45.1	80	22	16	1	56.2	34.0	22.2	36	1.58	...	...	10	15	9	7	NW	Mrs. L. H. Grenewald.

Mean temperature from maximum and minimum readings. * Extremes from dry thermometers. [1] Mean temperatures, 7 + 2 + 9 + 9 + 4. [2] Mean temperature 8 + 8 + ʚ † Died March 9.

CH, 1894.

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Delaware Basin.																																
Blooming Grove,		·07						·01							·22								·72		·09							1·11
Browers Lock,										·16					·16	·07			·05		·24	·45	·54		·04				·24			1·93
Coatesville,									·11		·02				·29				·05		·31	·48	·55		·05				·22			2·08
Coopersburg,							·01		·03	·01				·14	·19				·02		·18	·22	·43		·09				·28			1·60
Doylestown,						·15			·08						·16	·02					·25	·28	·27		·08				·09			1·38
Dyberry,									·01						·32						·09	·25	·79						·09			1·55
Easton,										·01						·12			·13		·02	·15	·47		·13	·02			·20			1·25
Forks of Neshaminy,							·05		·07			·13	·04		·20				·02		·27	·20	·40		·10				·22			1·70
Frederick,									·00					·03	·17				·03		·26	·20	·44		·08				·22			1·49
Hamburg,													·22		·24				·11			·10	·62						·24			1·53
Honesdale,									·04				·02		·24				·04		·02	·42	·71		·02		·02		·06			1·59
Kennett Square,							·08		·08	·03	·02		·01		·05	·09					·18	·08	·70		·03				·10			1·45
Lansdale,						·02			·13		·03				·24						·23	·26	·49		·04				·30			1·74
Mauch Chunk,		·05					·03						·02		·22				·09		·02	·21	·81		·02				·20			1·67
Ousville,									·06				·04		·18				·04			·39	·51		·12				·21			1·56
Philadelphia, a†							·03			·04	·03				·04	·13					·25	·19	·54		·03				·17			1·45
Philadelphia, b,							·03		·01	·08	·03		·01		·05	·17					·15	·24	·62		·05				·20			1·64
Philadelphia, c,							·05		·01	·06	·04		·02		·06	·15			·01		·20	·25	·59		·05				·21			1·70
Phœnixville,		·01					·01		·16		·02				·12				·06		·17	·41	·49		·06				·25			1·76
Point Pleasant,						·03									·20				·07		·14	·37	·23	·13	·02				·20			1·39
Pottstown,													·12		·15				·04		·22	·30	·58		·07				·26			1·74
Quakertown,							·03			·06				·03	·22				·10		·20		·71		·12				·21			1·68
Reading,							·02		·01						·15				·01		·25	·15	·43		·05				·25			1·32
Salem Corners,		·12						·12							·28				·03	·13		·03	·80		·08	·02	·05		·07			1·73
Seisholtzville,															·22				·05		·22	·15	·45		·07				·24			1·40
Skippack,																																...
Smith's Corner,							·05		·03	·05	·03			·04	·12	·06			·04		·17	·40	·29		·15	·03			·25			1·71
Swarthmore,						·08					·05		·05			·01					·30		·70						·15			1·34
West Chester,						·03		·14		·03				·15	·02						·25	·24	·65		·02				·14			1·67
Westtown,						·06		·10	·02						·10	·10					·30	·25	·46		·01				·20			1·60
Susquehanna Basin.																																
Altoona,															·27	·10			·04	·07			·32									·80
Aqueduct,							·03								·25				·15		·11	·14	·36						·05			1·09
Bloomsburg,													·01		·15				·15			*	*	*	*							·31
Blue Knob,						·09									·61				·31		·23		1·00			·10	·15					2·49
Carlisle,							·02								·22				·06		·14	·18			·22				·30			1·14
Driftoo,				*							*				·15	·10		*							*				·10			·35
Emporium,						·03	·10								·20				·12		·05	·30	·19						·25			1·24
Gettysburg,														·06		·13						·11	·60	·08					·23			1·21
Girardville,																																...
Grampian,							·15								·44				·14		·55	·24	·60						·15			2·27
Harrisburg,†							·08								·18	·03			·07		·07	·30	·44						·13			1·30
Hollidaysburg,															·62	·03			·09		·10	·33	·22	*					·05			1·44
Huntingdon,															·50				·16		·03	·18	·20									1·07
Kilmer,						·05									·33							·29	·36									1·03
Lancaster,															·40						·21	·13	·30						·45			1·49
Lebanon,							·03							·06	·22				·05		·15	·20	·59		·02				·16			1·48
Le Roy,							·04		·02						·15							·28	·43		·03	·02	·03					1·00
Lewisburg,							·05								·15	·30			·07			·22	·34									1·13
Lock Haven,						·02									·20				·13		·01	·40	·08									·84
Selins Grove,																						·35	·74									1·09
South Eaton,														·02	·20				·05			·16	·33		·03	·01						·80
State College,							·07						·07		·32				·16		·11	·21	·20									1·14
Wellsboro,															·20							·04										·24
Wilkes-Barre,		·02						·03							·26				·10			·04	1·00		·11				·12			1·68
York,							·04			·02			·01		·11				·04		·16	·13	·61		·14				·32			1·58

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Beaver Dam,						·26										·57			·03	·16	·02	·24	·70			·12			·04	·02		2·16
Brookville,							·12									·14			·12			·08	·73						·13	·02		1·34
Clarion,							·49							·01		·29				·06		·20	·80				·06	·01	·05	·03		2·00
Confluence,							·11									·70			·06	·25	·06	·30	·67	·06		·15						2·36
Davis Island Dam,							·35									·65			·06	·22	·08	·01	·79			·35	·08		·05			2·64
DuBois,							·19								·52							·19	·77						·29			1·96
Elwood Junction,							·31									·40				·14		·04	·78			·11	·06			·05		1·89
Freeport,							·29									·63			·03	·23	·03	·12	·82						·13			2·28
Greensboro,							·15									·65			·08	·20	·05	·45	·67	·02		·06				·03		2·36
Greenville,						·34	·02								·46				·09		·10	·47	·42					·04				1·94
Immel Reservoir,							·18								·60				·39		·25	·20	·63			·06						2·31
Indiana,																																...
Johnstown,						·05	·03									·72			·21		·13	·34	·43			·03	·01					1·95
Kane,						·20	·15								·20				·08		·37	·42	·42				·10		·30			2·24
Ligonier,						·11									·65				·30	·14		·60	·28		·01	·20						2·29
Lock No. 4,							·18					·01				·62			·14	·13	·02	·06	·77			·01	·01					1·95
Mahoning,							·30									·55			·02	·10	·03	·35	·92				·03		·21	·04		2·55
Meadville,																																...
New Castle,							·32							·39					·13				·45			·15						1·47
Oil City,							·31									·48				·08	·02	·10	·68				·08		·15			1·90
Parker's Landing,							·40									·48				·11	·02	·24	·72				·01		·10	·01		2·09
Pittsburg,†						·12	·04								·68				·38		·12	·38	·33			·31			·05			2·41
Ridgway,							·21									·18			·08			·24		·62			·01		·19			1·53
Saegerstown,							·06								·10								·60	·28			·50	·10	·10			1·74
Saltsburg,							·17									·66			·06	·12	·06	·05	·80	·02		·02	·03	·01	·07	·03		2·10
Shingle House,							·13								·30				·03		·13	·39	·40			·22	·07		·17			1·84
Smethport,							·15								·20			·30			·25	·33	·33				·10		·20			1·86
Somerset,							·15						·20		·25				·20		·15		·45			·45						1·85
Stoyestown,																·62			·08	·04	·13	·08	·03			·20	·30					1·48
Uniontown,						·21									·70				·45		·58	·46	·39		·02	·03	·04		·02			2·90
Warren,							·30									·21						·27	·85				·11	·10	·02	·01		1·87
West Newton,							·34									·57			·10	·20	·04	·09	·72			·10						2·16
Potomac Basin.																																
Chambersburg,						·01							·05		·28				·08		·09		·44						·22			1·17
McConnellsburg,																																...
Lake Basin.																																
Erie,†						·23	·11								·12				·01	·14	·06	·59	·37	·01	·01	·13	·01	·03	·13			1·95

† U. S. Weather Bureau Stations. * Missing.

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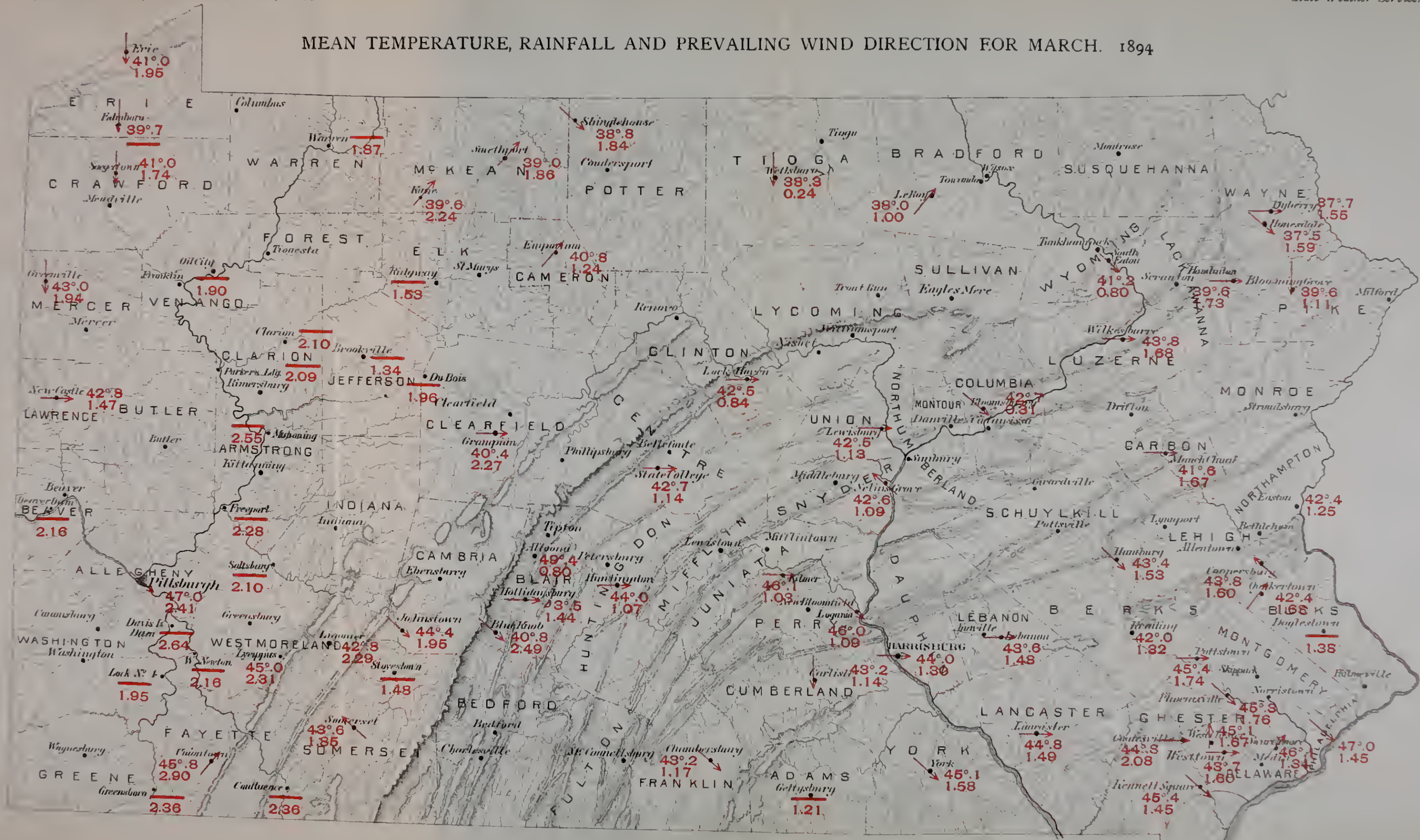
MEAN TEMPERATURE, RAINFALL AND PREVAILING WIND DIRECTION FOR MARCH. 1894



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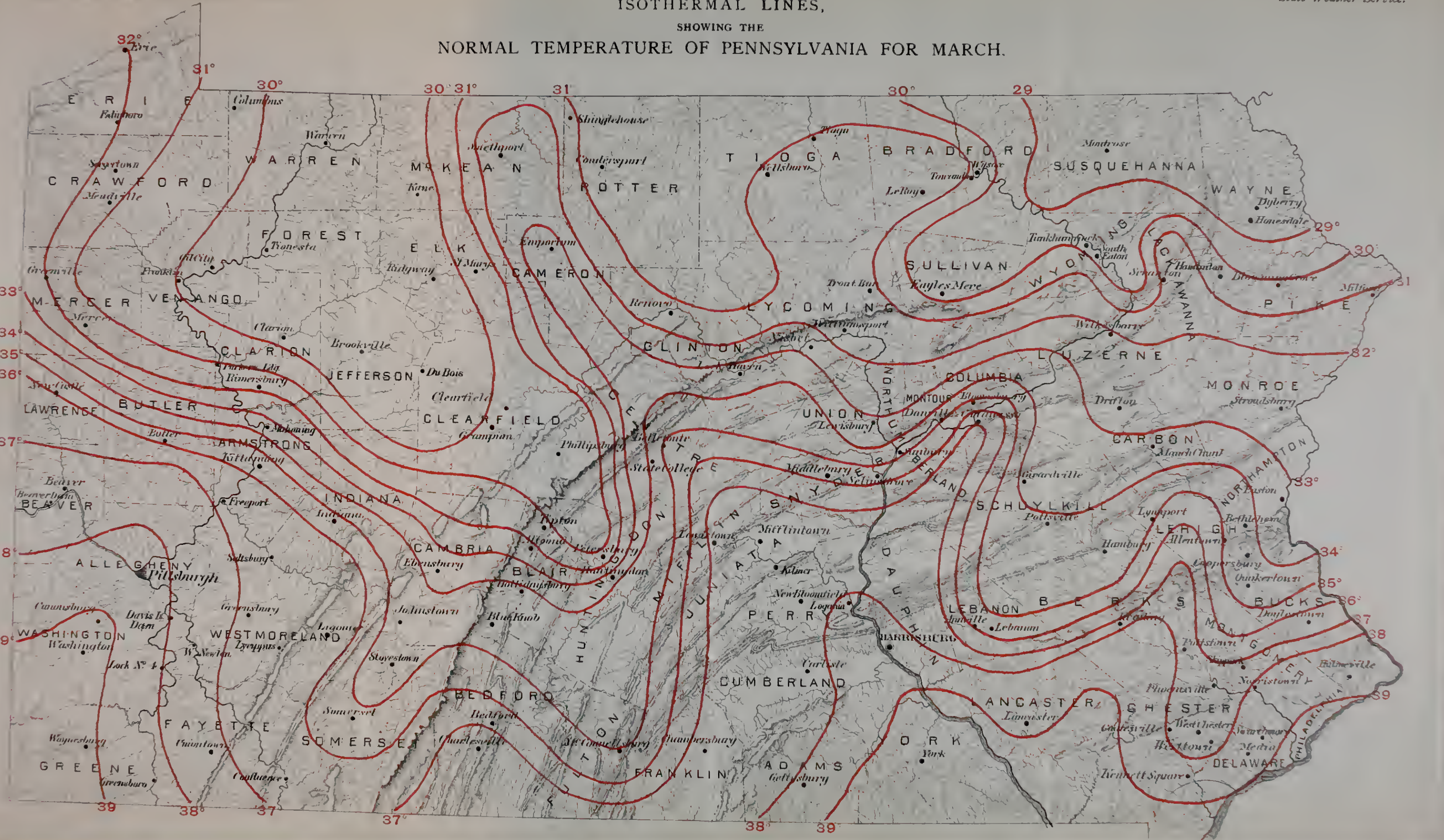
ISOTHERMAL LINES,

SHOWING THE

NORMAL TEMPERATURE OF PENNSYLVANIA FOR MARCH.



don, 15th, 22d; Kilmer, 22d; Lancaster, 22d; Lebanon, 22d; Coopersburg, 13th, 15th, 22d; Logania, 15th, 22d; *Philadelphia* [Weather Bureau], 23d; [Centennial Avenue], 23d; [Locust Street], 22d, 23d; Wellsboro, 13th, 15th, 21st, 22d; Lewisburg, 15th; Dyberry, 2d; Hamilton, 2d; Ligonier, 15th, 22d; York, 15th.

Hail.—Blue Knob, 15th; Johnstown, 15th; Emporium, 15th; Phœnixville, 15th; Carlisle, 15th; Somerset, 13th, 15th; Wellsboro, 15th; Hamilton, 2d; York, 15th.

Snow.—Blue Knob, 26th, 27th; Hollidaysburg, 26th, 27th, 28th; Le Roy, 15th, 25th, 26th, 27th; Emporium, 15th, 29th; State College, 15th; Grampian, 15th, 26th, 29th; Lock Haven, 15th; Uniontown, 25th; Wilkes-Barre, 15th; *Philadelphia* [Centennial Ave.], 15th, 26th, 27th; Selins Grove, 15th.

Sleet.—Blue Knob, 15th; Hollidaysburg, 15th; Quakertown, 15th; Johnstown, 15th; Emporium, 15th; State College, 15th; Grampian, 15th; Lock Haven, 6th, 15th; Kilmer, 15th; Coopersburg, 15th; Wilkes-Barre, 15th; Kane, 15th; Greenville, 15th; Logania, 15th; *Philadelphia* [Centennial Avenue], 15th; Honesdale, 15th; Ligonier, 15th, 22d.

Aurora.—Blue Knob, 31st; Le Roy, 30th; Quakertown, 30th; Johnstown, 29th; Emporium, 30th; Mauch Chunk, 30th; State College, 30th; West Chester, 30th; Coatesville, 30th; Kennett Square, 30th; Phœnixville, 30th; Westtown, 30th; Grampian, 30th; Lock Haven, 30th; Bloomsburg, 30th; Saegerstown, 30th; Carlisle, 30th; Harrisburg, 30th; Edinboro, 30th; Chambersburg, 30th; Kilmer, 30th; Lancaster, 30th; Lebanon, 30th; Coopersburg, 30th; Kane, 30th; Greenville, 30th; Pottstown, 30th; Logania, 30th; *Philadelphia* [Weather Bureau], 30th; [Centennial Avenue], 30th; Shingle House, 30th; Selins Grove, 30th; Somerset, 30th; Wellsboro, 30th; Dyberry, 30th; Honesdale, 30th; Hamilton, 30th; Ligonier, 30th; South Eaton, 30th; York, 31st.

Coronæ.—Blue Knob, 18th; *Philadelphia*, [Locust Street], 19th, 20th; York, 31st.

Solar Halo.—Le Roy, 6th, 10th, 30th; *Philadelphia* [Weather Bureau], 9th, 12th, 15th, 20th, 28th; [Centennial Avenue], 12th, 13th, 15th, 20th, 28th; Selins Grove, 28th.

Lunar Halo.—Blue Knob, 12th, 17th; Emporium, 12th; State College, 19th, 21st; Lancaster, 17th, 18th; *Philadelphia* [Weather Bureau], 17th; [Centennial Avenue], 17th; Shingle House, 22d.

Parhelia.—Lebanon, 28th.

Meteor.—Selins Grove, 4th.

MAY WEATHER.

From United States Weather Bureau Records.

The following data, compiled from the records of observations taken during the length of time given at each station, show the average and extreme conditions during that time, and also the range within which weather variations may be expected to keep in any future May.

	Philadelphia. (23 years.)	Pittsburgh. (23 years.)	Erie. (20 years.)
Mean or normal,	62°	62°	56°
Warmest May, Average,	1880 69°	1880 69°	1880 65°
Coldest May, Average,	1882 57°	1882 57°	1882 51°
Highest temperature recorded, Date,	96° 26th, 1880	95° 3d, 1887	91° 30th, 1879
Lowest temperature recorded, Date,	36° 1st, 1880; 6th, 1891	27° 1st, 1876	31° 3d, 1885
Average date of last "killing" frost (spring),	April 9th	April 27th	April 30th
Average precipitation (inches),	3·01	3·45	3·86
Average number of days with ·01 inch or more,	12	14	13
Greatest monthly precipitation, Date,	5·83 1873	6·45 1889	8·05 1892
Least monthly precipitation, Date,	0·54 1880	0·98 1871	1·04 1879
Greatest amount in 24 hours, Date,	1·89 7th and 8th, 1886	2·96 10th and 11th, 1889	4·71 16th and 17th, 1893
Greatest amount snowfall in 24 hours, Date,	0	Trace 3d, 1885	2·00 9th, 1885
Average number clear days, Partly cloudy, Cloudy,	9 12 10	8 13 10	10 12 9
Prevailing direction of wind,	SW	NW	W
Highest velocity, miles per hour, Date,	60 10th, 1889	36 9th and 12th, 1875	60 1875

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

T. F. Townsend, Weather Bureau, L. F. O. in Charge.

MONTHLY WEATHER REVIEW.

For April, 1894.

Hall of the Franklin Institute,
Philadelphia, April 30, 1894.

GENERAL REVIEW.

The average temperature for March was 48°·0, which is normal.

The average rainfall, 3·62 inches, is an excess of 0·34.

The warmest days were the 17th, 18th, 19th, 20th, 27th, 28th and 30th, and most stations report the 3d as the coldest.

Precipitation was general on the 4th, 5th, 6th, 7th, 8th, 10th, 11th, 19th, 20th, 21st, 22d and 28th. That of the 10th and 11th was a remarkably heavy snowstorm, being particularly severe in the interior and eastern portions of the State. Over two feet of snow fell in some sections and interrupted travel for a short time. The damage to fruit by this storm was less than at first estimated, but many trees were broken and injured, and some early peaches killed.

A heavy hail, rain and thunderstorm, amounting to 5·95 inches, occurred at Somerset on the 28th.

From January 1, 1894, to April 30, 1894, the excess in temperature at Philadelphia was 338°; at Erie, 395°, and at Pittsburgh, 416°.

For the same period the deficiency in precipitation at Philadelphia was 3·32; Erie, 3·22; and Pittsburgh, 0·54.

TEMPERATURE.

	Mean Temperature.	*Mean Precipitation, Inches.*
April, 1888,	46°·5	2·52
1889,	48°·7	4·50
1890,	48°·7	3·46
1891,	49°·8	2·08
1892,	47°·0	2·04
1893,	47°·6	4·74
1894,	48°·0	3 62

The means of the daily maximum and minimum temperatures, 58°·6 and 37°·4, give a monthly mean of 48°·0, which is the normal for the State, and 0°·4 above the corresponding month of 1893.

The average daily range was 21°·2.

Highest monthly mean, 53°·3 at Kilmer.

Lowest monthly mean, 41°·9 at Wellsboro.

Highest temperature recorded during the month, 83° on the 27th at Kilmer.

Lowest temperature, 5° on the 5th at Drifton.

Greatest local monthly range, 69° at Dyberry.

Least local monthly range, 49° at Harrisburg.

Greatest daily range, 50° at Hollidaysburg and Drifton.

BAROMETER.

The mean pressure for the month, 30·06, is about ·06 above the normal. At the United States Weather Bureau Stations, the highest observed was 30·45 at Philadelphia on the 30th, and the lowest 29·45 at Philadelphia on the 11th.

PRECIPITATION.

The average precipitation, 3·62 inches for the month, is an excess of 0·34. The largest totals in inches (including melted snow) were Somerset, 10·00; Wellsboro, 8·69; Lock Haven, 6·42; Le Roy, 6·12; Shingle House, 5·61, and Salem Corners, 5·32.

The least were Altoona, 1·69; Erie, 1·74; Easton, 1·90; Chambersburg, 1·96; Frederick, 2·03, and Beaver Dam, 2·22.

The largest monthly snowfall totals in inches were Salem Corners, 38·2; Lock Haven, 36·0; Selins Grove, 33·0; Le Roy, 32·5; Hamburg, 30·0, and Coatesville, 29·2.

WIND AND WEATHER.

The prevailing wind was from the Northwest.

Average number: rainy days, 11; clear days, 11; fair days, 8; cloudy days, 11.

MISCELLANEOUS PHENOMENA.

Thunder Storms.—Le Roy, 4th, 20th; Quakertown, 20th; Johnstown, 19th, 20th, 28th; Emporium, 20th; State College, 19th, 27th, 28th; West Chester, 20th; Coatesville, 20th; Kennett Square, 16th, 20th, 28th; Phœnixville, 20th, 28th; Grampian, 19th; Lock Haven, 4th, 20th; Bloomsburg, 4th, 5th, 7th, 20th; Saegerstown, 20th; Uniontown, 19th; Carlisle, 20th, 27th, 28th; Huntingdon, 19th, 20th; Kilmer, 20th, 27th, 28th; New Castle, 28th; Coopersburg, 20th, 27th; Pottstown, 20th; Kane, 27th; *Philadelphia* [Weather Bureau], 20th, 28th; [Centennial Avenue], 4th, 20th, 28th; [Locust Street], 20th; Shingle House, 19th, 20th; Selins Grove, 20th, 28th; Somerset, 19th; Wellsboro, 4th, 20th; Lewisburg, 20th, 28th; Dyberry, 20th; Honesdale, 20th; Ligonier, 19th, 20th, 28th; South Eaton, 20th.

Hail.—Le Roy, 20th; Quakertown, 21st; Cassandria, 20th, 22d, 29th; Phœnixville, 10th; Lock Haven, 5th; Bloomsburg, 20th; Sagerstown, 27th;

Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for April, 1894.

Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for April, 1894.

County.	Station	Elevation above Sea Level (feet).	Temperature. Mean	Maximum Highest.	Maximum Date.	Minimum Lowest.	Minimum Date.	Mean of Maximum.	Mean of Minimum.	Daily Range. Mean.	Daily Range. Greatest.	Precipitation. Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rain or Snow	Number of Days. Clear.	Fair.	Cloudy.	Wind. Prevailing Direction.	Observers
Allegheny,	Pittsburgh,	820	51·0	82	18	24	9	61·[illegible]	40·8	20·2	32	3·63	...	..	12	12	7	11	NW	O. D. Stewart, W. B.
Berks,	Hamburg,	380	49·2	80	27	18	3	59·1	39·2	19·9	40	3·[illegible]5	30·0	.	8	8	13	9	NW	William Shipe.
Berks,	Reading,[2]	280	49·9	...	...	...	...	...	...	...	...	5·40	...	.	13	...	...	...	...	Franklin Yager.
Blair,	Altoona,	1,181	53·0	78	21	27	3	63·0	44·1	17·9	29	1·69	...	.	9	...	...	...	...	Dr. C. B. Dudley.
Blair,	Hollidaysburg,	947	48·6	81	27, 28	14	3	62·7	34·5	28·2	50	3·[illegible]0	6·0	..	10	14	8	8	W	Prof. J. A. Stewart.
Bradford,	Le Roy,	1,400	42·8	73	30	16	3	5[illegible]·9	34·7	16·2	36	6·12	32·5	...	16	7	9	14	SW	G. W. T. Warburton
Bucks,	*Forks of Neshaminy,[1]	304	51·6	..	...	...	...	...	...	...	..	3·20	.	...	9	17	6	7	N	J. C. Hilsman.
Bucks,	Quakertown,	536	48·0	77	27	18	3	58·5	37·4	21·1	33	2·27	7·0	...	10	4	21	5	SW	J. L. Heacock.
Cambria,	Cassandria	2,100	47·8	74	28	20	3, 9	55·6	40·0	15·6	32	3·78	19·0	...	12	5	12	13	NW	A. H. Boyle.
Cambria,	Johnstown,	1,184	50·0	82	28, 30	20	3	61·5	38·5	23·0	44	3·09	5·0	...	12	6	10	14	S	E. C. Lorentz
Cameron,	Emporium,	1,050	46·7	79	30	16	3	58·0	35·4	22·6	45	3·89	18·4	...	11	11	9	10	W	T. B. Lloyd.
Carbon,	E. Mauch Chunk,	550	47·2	75	27	16	3	58·4	35·9	22·5	44	3·58	17·5	...	11	13	8	9	N	F. C. Wintermute
Centre,	State College—																			
	Agricultural Experiment Sta.,	1,191	46·8	74	27, 30	18	3	55·8	37·7	18·1	34	3·85	20·5	...	11	11	4	15	W	Prof. Wm. Frear.
Chester,	West Chester,	455	47·6	76	28	23	3	58·8	40·4	18·4	31	3·61	7·5	...	13	16	7	7	NW	J. C. Green, D.D.S.
Chester,	Coatesville,	380	49·4	79	27	19	2	60·8	38·0	22·6	41	4·20	29·2	.	10	12	10	8	W	W. T. Gordon.
Chester	Kennett Square,	275	49·4	78	28	21	3	60·2	38·6	21·6	37	3·80	8·8	...	11	15	5	10	S	B. P. Kirk.
Chester,	Phœnixville,	190	50·6	78	27	21	3	61·4	40·8	19·6	35	2·64	12·0	...	13	10	6	14	NW	Knowles Croskey.
Chester,	Westtown,	350	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	John D. Carter.
Clearfield,	Grampian,	1,450	46·4	76	30	16	3	5[illegible]·7	36·2	20·5	38	2·98	12·0	...	10	12	4	14	SW	Nathan Moore.
Clinton,	Lock Haven,	560	49·4	82	30	17	3	62·5	39·2	20·3	45	6·42	36·0	...	13	14	1	15	W	Prof. J. A. Robb.
Columbia,	Bloomsburg,—																			
	State Normal School,	500	48·2	76	27	20	3	57·4	39·0	18·4	35	4·58	18·0	...	13	15	4	11	NW	Prof. J. G. Cope.
Crawford,	Meadville—																			
	Divinity Hall,	1,200	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...		Prf. J. H. Montgomery.
Crawford,	Saegerstown,	1,200	46·0	83	30	15	3	58·6	33·3	25·3	46	2·55	0·8	...	8	6	11	13	NW	J. G. Apple.
Cumberland,	Carlisle,	480	50·0	78	27	20	3	60·6	39·5	21·1	39	3·61	18·5	...	10	15	4	11	S	J. E. Pague.
Cumberland,	Carlisle—																			
	Dickinson College,	480	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	H. E. Smith.
Dauphin,	Harrisburg,	361	50·0	76	27	27	3	58·0	41·0	17·0	31	2·27	18·0	.	11	12	5	13	N	F. Ridgway, W. B.
Delaware,	Swarthmore—																			
	Swarthmore College,	190	51·2	83	28	24	3	60·3	42·[illegible]	18·3	32	2·63	5·0	..	6	8	15	7	NW	Prof. S. J. Cunningham.
Erie,	Edinboro,*[1]	1,400	45·3	74	30	20	3, 9	...	...	...	...	...	15·0	...	..	...	...	...	W	C. F. Sweet.
Erie,	Erie,	681	45·0	77	19	24	3	52·0	38·0	14·0	33	1·74	...	...	12	8	16	6	NE	P. Wood, W. B.
Fayette,	Uniontown,	1,000	50·1	81	10	22	3	59·0	41·2	17·8	36	3·50	...	...	11	9	15	6	NW	Wm. Hunt.
Franklin,	Chambersburg,	618	48·2	76	20, 27	20	3	59·8	36·7	23·1	40	1·90	...	...	9	10	9	11	NW	J. C. Boggs.
Fulton,	McConnellsburg,	875	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	..	T. F. Sloan.
Huntingdon,	Huntingdon—																			
	The Normal College,	650	48·8	79	27	16	3	62·5	35·2	27·3	46	3·10	9·0	...	10	15	7	8	W	Prof. W. J. Swigart.
Indiana,	Indiana—																			
	State Normal School,	1,350	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Prof. S. C. Schmucker.
Juniata,	Kilmer,*[2]	475	53·3	83	27	18	2	...	...	...	.	4·86	28·1	..	11	11	6	13	W	R. J. Mickey.
Lancaster,	Lancaster—																			
	Franklin and Marshall Col'ge,	413	49·2	76	20, 27	23	3	59·4	39·0	20·4	34	4·30	17·5	.	10	14	11	5	NW	W. E. Bushong.
Lawrence,	New Castle,	932	47·4	81	18	15	3	60·5	34·4	26·1	45	2·94	0·2	.	7	11	11	8	S	Wm. T. Butz.
Lebanon,	Lebanon,	458	48·4	77	27	17	3	59·1	37·8	21·3	38	4·77	25·2	.	12	13	7	10	NW	G. W. Hayes, C.E.
Lehigh,	Coopersburg,	520	49·4	77	22	20	3	59·5	39·3	20·2	35	3·18	10·0	.	9	13	12	5	NW	Dr. M. H. Boye.
Luzerne,	Drifton (25 days),	1,683	42·4	73	27	5	5	57·8	27·0	30·8	50	4·52	13·5	.	10	8	5	12	N	J. R. Wagner.
Luzerne,	Wilkes-Barre,	575	48·4	80	30	18	3	60·6	36·2	24·4	43	3·41	14·0	.	9	16	2	12	W	A. W. Betterly.
McKean,	Kane,	2,000	43·4	76	30	15	9	54·3	32·6	21·7	34	3·39	13·5	..	12	12	7	11	SE	C. H. Kemp.
McKean,	Smethport,	1,500	43·[illegible]	78	30	14	3	55·4	32·3	23·1	47	4·22	...	.	9	10	8	12	SE	Armstrong & Brownell.
Mercer,	Greenville—																			
	Thiel College,	1,000	47·6	80	18	18	3	60·0	35·3	24·7	40	2·55	1·5	..	9	15	6	9	S	Prof. S. H. Miller.
Montgomery,	Pottstown,	150	51·4	81	27	24	3	61·8	41·1	20·7	36	3·20	5·0	.	7	16	7	7	W	Charles Moore, D.D.S.
Montgomery,	Skippack,	...	...	...	...	...	...	...	...	.	...	...	...		.	..	.	.	...	B. W. Dambly.
Northampton,	Easton—																			
	Lafayette College,	325	49·2	76	27	20	3	58·7	39·8	18·9	34	1·90	4·5		6	12	7	11	...	J. W. Moore
Perry,	(Aqueduct) Logania,	367	51·4	82	27	19	3	61·0	41·8	19·2	3[illegible]	4·29	21·0	.	14	13	6	11	NW	Richard Callin.
Philadelphia,	U. S. Weather Bureau,	117	52·0	77	28	27	3	60·0	43·0	17·0	28	2·69	1·2		10	13	7	10	NW	L. M. Dey, W. B.
Philadelphia,	1529 Centennial Avenue,	120	52·0	80	28	25	3	61·4	42·6	18·8	30	3·22	2·2		11	13	10	7	NW	John Comly.
Philadelphia,	3911 Locust Street,	100	51·0	77	28	26	3	60·2	41·8	18·4	31	3·52	2·0		11	13	5	12	NW	R. L. Paddock
Pike,	Blooming Grove,*[1]	...	45·0	79	27	26	3, 11	.	...	.		2·75	6·8	.	10	..	.	..	S	John Grathwohl.
Potter,	Shingle House,	1,475	43·0	79	30	11	3	54·7	31·2	23·5	48	5·01	21·1	.	16	11	4	15	W	C. D. Voorhees, M. D.
Schuylkill,	Girardville,	1,000		.	...	.	.	.		.			.		..	...	.	.		E. C. Wagner.
Snyder,	Selins Grove (26 days),	455	46·2	79	27	27	5, 16	57·6	31·8	22·8	43	4·86	33·0	.	9	.	18	8	SW	J. M. Boyer.
Somerset,	Somerset,	2,250	46·7	76	30	18	3	58·6	34·8	23·8	44	10·00	0·0	.	10	3	14	13	SW	W. M. Schrock.
Tioga,	Wellsboro,*[1]	1,327	41·9	71	27, 30	14	3		.	..		8·61	46·0	...	12	13	5	12	N	H. D. Deming
Union,	Lewisburg,	450	47·4	78	27	17	3	59·0	35·9	23·1	41	4·28	26·5		14	14	4	12	S	Prof. W. G. Owens.
Wayne,	Dyberry,	1,100	43·8	78	17	9	3	55·4	32·4	23·1	41	2·51	19·5	...	11	13	1	16	NW	Theodore Day.
Wayne,	Honesdale,	1,000	41·8	72	17, 30	13	3	55·0	31·7	20·3	36	3·[illegible]0	21·0	...	14	15	3	12	NW	Andrew Thompson
Wayne,	(Salem Corners) Hamlinton,	1,600	44·8	76	30	17	2	52·4	37·3	15·1	34	5·32	38·2	.	16	10	5	15	NW	T. B. Orchard, M. D.
Westmoreland,	(Tunnel Reservoir) Lycippus,	1,420	49·5	80	19	22	9	58·2	40·8	17·4	27	3·99	2·8	..	10	...	.	..	.	Murray Forbes
Westmoreland,	Ligonier,	1,750	48·4	80	17, 30	17	3	61·2	45·6	15·6	42	4·71	...	...	11	12	11	7	.	C. D. Ambrose
Wyoming,	South Eaton,	660	45·8	74	27, 30	15	3	55·4	36·2	19·2	39	2·70	8·0	...	13	13	4	13	NW	B. M. Hall
York,	York,	385	49·8	78	27	21	3	61·1	38·5	22·6	40	4·48	26·0	...	12	11	14	5	NW	Mrs. L. H. Grenewald.

Mean temperature from maximum and minimum readings. * Extremes from dry thermometers. [1] Mean temperatures, 7 + 2 + 9 + 9 ÷ 4 [2] Mean temperature 8 + 8 ÷ 2

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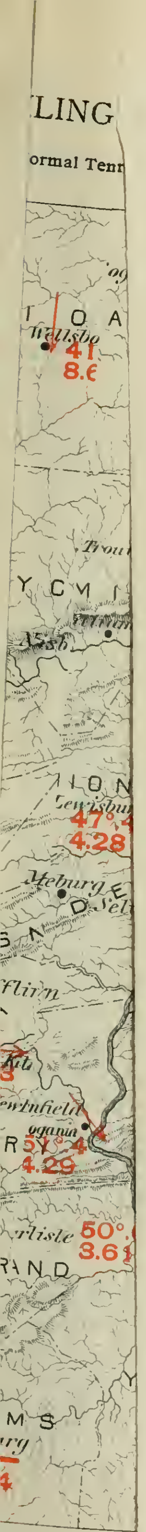
Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin.																																
[illegible] Grove,				'29		'31	'11	'25		'41									'30		'37	'36		'10				'25				2'75
[illegible] Lock,				'33	'02			'19		'46	'98	'03									'36	'09										2'46
Coatesville,				'53	'02			19		'7	1'85	'10							'01		'30	'18		'05								4'20
Coopersburg,				'02		'03	'07	'04		44	1'29								'01		13	'55										3'18
Doylestown,				'49				'14		'55	1'09	'06									'35	'12										3'30
Dyberry,					'12	'05	'36	'18		'30	'70	'32								'03	'22	'16						'19				2'51
Easton,					'37		'05				'85									'02		'60						'01				1 90
Forks of Neshaminy,				'45	'03		'02	'14			1'46										'45	'60		'02				'13				3'20
Frederick,				'43			'03	'2		'16	'81									'03	'18	'19						'08				2'03
Hamburg,				'66			'31			'83	1'00	'33								'09		'25						'06				3'55
Honesdale,				'15	'17	'02	35	'17		'23	1'07	'30								'04	'22	'28	'04	'04				'20				3'30
Kennett Square,				'57	'19			'19		1'20	1'19	'09					'01			'03	'30	'09						'04				3'80
Lansdale,				'50	'03			'18		'48	.63	'03								'52		'18						'06				2'61
Mauch Chunk,				'1		'08	'20	'23		'32	1'60	'11							'05		'34	'35						'04				3'58
[illegible]sville,				'65	'01		'05			'27	'46	'02								'01	'19	'53						'01				2'23
Philadelphia, a†				57	'07		'02	'30		'70	'84										'30	'14						'02	'03			2'99
Philadelphia, b.				50	'05		'03	'30		'70	'92	'01									'38	'17						'03	'05			3'.2
Philadelphia, c.				'62	'06		'03	'30		'65	1'20	'01									'40	'18						'03	'04			3'52
Phoenixville,				'34			'06	'14		'43	'98	'02					'01		'02	'35	'10	'03		'04				'06				2'64
Point Pleasant,				'53			'03			'10	1'40	'36									'73	'57		'02								3'74
Pottstown,				'65			'10	'20			1'75									'30		'10						'10				3'20
Quakertown,				'58		'05	'06	'08			'79	'27								'03	'20	'63						'03				2'72
Reading,				'55			'15	'05		'60	1'55	'20					'01		'01	'01	'15	'07		'01				'04				3'40
Salem Corners,				'15	'17	'18	'08	'56			2'40	'75	'01						'05	'04	'19	'35		'08	'03			'23	'05			5'32
Seisholtzville,				'5			'05			'20	1'32	06									'68											3 06
Skippack,																																
Smith's Corner,				'56				'15		'20	1'29										'28	'46										2'94
Swarthmore,				'50				'42				1'20									'36	'11						'01				2'60
West Chester,				'60			'04	15		99	1'45	'06					'03		'01	'03	'31	'10		'01				'03				3'81
Westtown,																																
Susquehanna Basin.																																
Altoona,							'08	'14		'22	'35								'03	'60	'20							'04	'03			1'69
Aqueduct,				'18	'01		'14	'01		'79	1'96	'08								'04	'82	'07		'03			'08	'05				4'29
Bloomsburg,				'64	'11	'03	'22	'02		'40	1'40						'04		'06	'01	1'15	48	'02									4'58
Carlisle,				'13			'17			'63	'95	'20							'02		1'03		'13			'20		'15				3'61
Drifton,	*			'46	'11	'15	'20	*		'20	'75	'50			*					'37	1'40	*	'38						*			4'52
Emporium,				'15	'08		'51			'40	'74								'22	'82	'24	'26	'30					'17				3 89
Gettysburg,				'23	'30			'18		'04	1'68	'37								'04	'56	'13						'07	'34			3'94
[illegible]ardville,																																
Grampian,				'20		'08	'50			'30	'48								'72	'20	'22	'12						'16				2'98
Harrisburg,†				'18			'20	'02		'36	1'04	'02							'02	'04	'28	'08						'03				2'17
Hollidaysburg,				.04	'09		'32			'66	'63	'03							'59	'56								'10	'06			3'08
Huntingdon,							'35			'70	'68	.10							'12	'68	'29	'07	'10					'10				3'19
Kilmer,				'10		'10	'20			1'21	1'87								'10	'80	'31	'11					'01	'05				4'86
Lancaster,				'70			'30			'35	1'30	'50					'03			'01	'52	'50						'07				4'30
Lebanon,				'50			'23	'02		'75	2'11	'21					'02	'03	'56	'26		'01						'07				4'77
Le Roy,				'15	'03	'04	'31	'15		'15	2'20	'40							'08	'58	'63	'80	'30	'03			'02	'45				6'12
Lewisburg,				'08	'05		'15	'43		'40	1'80	'15					'02		'11	'12	1'25	'67	'01					'04				4'28
Lock Haven,				'16	'15		'44			1 00	2'20	'20					'04		'29	1'38	'04	'40	'06					'06				6'42
Selins Grove,				'01			'40	'05		'07	2'80									'10	1'00	'40						'03				4'86
South Eaton,				'06	'14	'07	'16	'10		'25	'81	'06							'06		'50	'26		'03				'26				2'76
State College,				'04	.01		'30			'50	1'30								'24	'80	'26	'26	'07					'07				3'85
Wellsboro,				'08			'55			'35	1'40	'55				'65			'15	'50	1'36	2'00	1'65					'05				8'69
Wilkes-Barre,				'13	'14		'15				1'90								'10	'29		44	'05					'21				3'41
York,				'45	'06		'11	'10		90	1'69	'32							'01		'58	'07						'10	'09			4'48

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Beaver Dam,			'05	'02		'01	'05	'20		22	'71								'08	'56	05	'05										[illegible]
Brookville,				'11	'07			47		'12	53	'08							12	'96	23		'06									[illegible]
Cassandria,	'03			'11	'07	'30	'27	05		'14	'50	'30							'97	'20												[illegible]
Clarion,	'07			'13	'06	'03	'13	'68		'15	1'13	'05							'20	1'4	[illegible]											[illegible]
Confluence,	'11			'11	'15	'25		'78		'44	1'17	13							'11	'55	'06	'02										[illegible]
Davis Island Dam,				'06	'01	'13	'03	'32		38	'70	'11							'15	1'08	27	[illegible]										[illegible]
DuBois,				'06	'27	'11	'12	'57		'09	'72	'06								'92	'06	13										[illegible]
Elwood Junction,				'06	'02	'03	'01	'22		'19	'52	'02							'18	'74	'06	'03	'01									[illegible]
Freeport,					'06	'14	'04	'38	'28	'91	'12								'23	'22	'09											[illegible]
Greensboro,				05		'16		'75		'30	'40	'10							'20	'40	'02	'07	'06									[illegible]
Greenville,				'30	'08		'64			'45									'47	'47		08										[illegible]
Immel Reservoir,				'05			'25	'20		'86		'33							'47	'72	'10	'20										[illegible]
Indiana,																																
Johnstown,	'05			'12	'15	'09	'14	'06		'47	'31								'54	'72		'09										[illegible]
Kane,	'08			'25	'10	'03	'65			'45	'35									1'11	'02		'11									[illegible]
Ligonier,				'25	'14	'10	'40			'45	'20								'65	'80		'20										[illegible]
Lock No. 4,				'01		'18		'44		'46	67	'05							04	'83	'04	'03										[illegible]
Mahoning,				'08	'09	'10	'07	'34		'16	1 06								'29	1'37	'04		'21									[illegible]
Meadville,																																
New Castle,						'10	'32				'62								'32	1'06	'15											[illegible]
Oil City,	'02			'17	'05	'10	'11	'50		'15	'70								'39	'68				'02								[illegible]
Parker's Landing,	'03			'08	'05	'14	'04	'55		'10	1'21	'04								1'31	19		12									[illegible]
Pittsburg,†				'09	'08	'03	'36	'01		'7	'25								'69													[illegible]
Ridgway,	'09			'05	'05	'01	'06	'42		'01	'65	'05								1'08			'22									[illegible]
Saegerstown,							'30			'05									'60	'10												[illegible]
Saltsburg,				'02	'01	'22	'02	'28		'24		'03							'05	'70	'06	'02										[illegible]
Shingle House,	'03			'20	'08		'33	'03		'50		'05					'03		'06	1 12	'14	82	62	'01								[illegible]
Smethport,				'20			'45			'40	1'20									'15	'15	25	'22					20				[illegible]
Somerset,						'35	'45			'25	45									'25	'90		'25									[illegible]
Stoyestown,	'05			'37	'30					'45	'20	'47							'03		'39	'10										[illegible]
Uniontown,				'06	'05		'76			49	'36								1'00	'13		'02										[illegible]
Warren,				'48	'19	'08	'10	'04		'12	'23	'03							'01	'94	'08											[illegible]
West Newton,				'02		'12		'37		'43	'42	'07							'05	'93	'03	'08										[illegible]
Potomac Basin.																																
Chambersburg,				'14						'62	'48	'02								31	'22	'09										[illegible]
McConnellsburg,																																
Lake Basin.																																
Erie,†				'04	'01		45			'04	'03								'55	'19	'06	[illegible]	04									[illegible]

† U. S. Weather Bureau Stations. * Missing.



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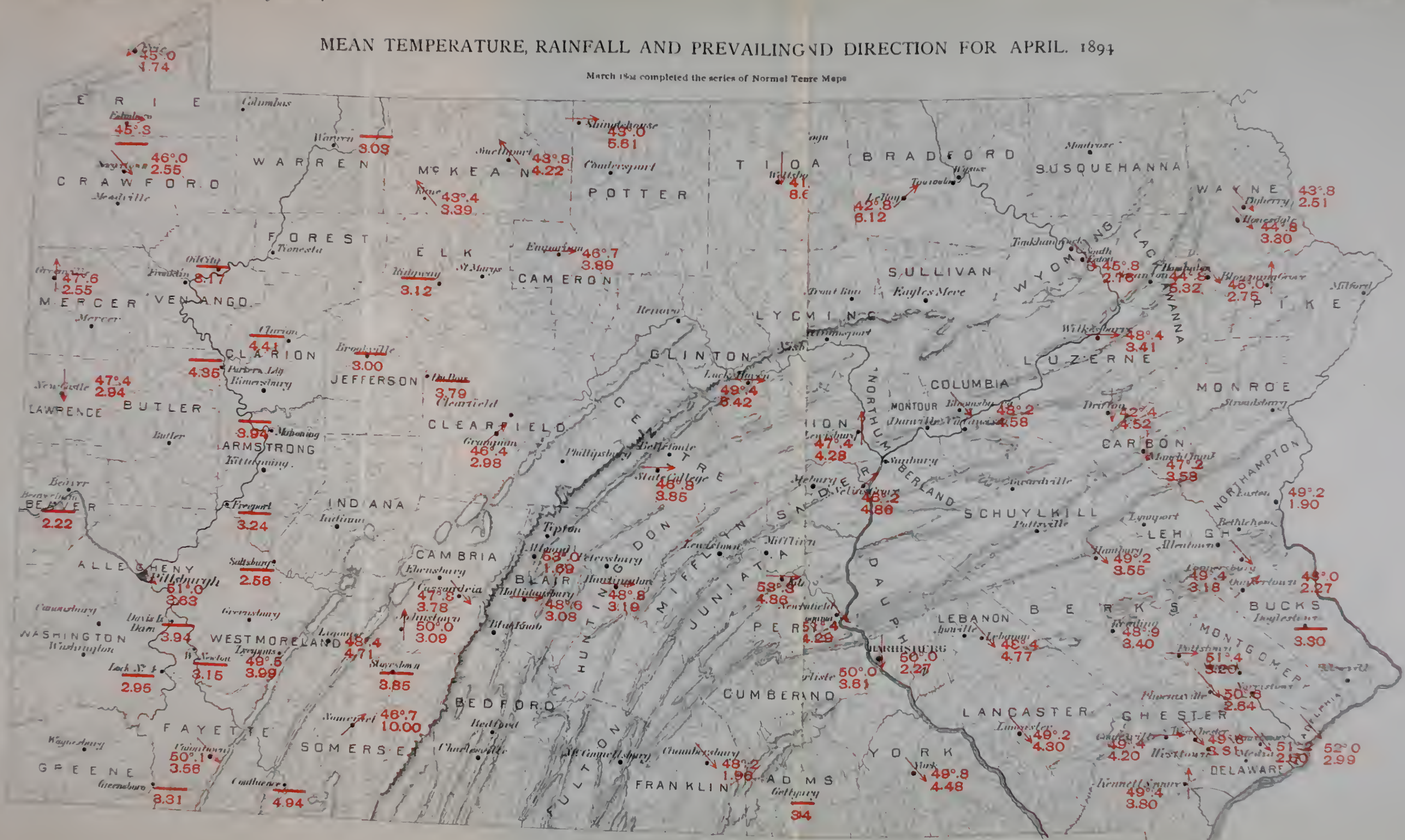
MEAN TEMPERATURE, RAINFALL AND PREVAILINGND DIRECTION FOR APRIL, 1894

March 1894 completed the series of Normal Temp. Maps



Carlisle, 20th; Huntingdon, 20th; Greenville, 20th, 28th; *Philadelphia* [Centennial Avenue], 20th; Shingle House, 4th; Selins Grove, 20th; Somerset, 28th; Lewisburg, 20th; Ligonier, 28th; York, 4th, 20th, 28th.

Snow.—Hollidaysburg, 7th; Cassandria, 5th, 7th; Johnstown, 10th, 11th; Emporium, 10th, 11th; Mauch Chunk, 6th, 7th, 10th, 11th; West Chester, 10th, 11th; Coatesville, 10th, 11th, 12th; Kennett Square, 10th, 11th, 12th; Phœnixville, 7th, 10th, 11th; Grampian, 5th, 7th, 10th, 11th; Lock Haven, 7th, 10th, 11th, 12th; Bloomsburg, 10th, 11th; Carlisle, 10th, 11th; Harrisburg, 10th, 11th; Huntingdon, 10th, 11th; Kilmer, 10th, 11th; Lancaster, 10th, 11th, 12th; New Castle, 7th; Lebanon, 7th, 10th, 11th, 12th; Coopersburg, 10th, 11th; Drifton, 4th, 6th, 7th, 10th, 11th; Wilkes-Barre, 10th, 11th; Kane, 7th, 10th, 11th; Smethport, 7th, 10th, 11th; Pottstown, 11th; Easton, 11th; *Philadelphia* [Centennial Ave.], 6th, 7th, 10th, 11th; Shingle House, 7th, 8th, 10th, 11th, 12th; Somerset, 10th; Lewisburg, 10th, 11th, 12th; York 10th, 11th, 12th.

Sleet.—Le Roy, 5th; Cassandria, 7th, 10th; Phœnixville, 10th; Coopersburg, 11th; Kane, 10th; Logania, 4th, 8th; *Philadelphia* [Locust Street], 6th, 10th; Somerset, 10th, 11th; York, 10th, 11th.

Frost.—Hollidaysburg, 2d, 3d, 6th, 9th, 16th, 26th; Quakertown, 3d, 5th, 9th, 15th, 16th, 23d, 24th, 26th; Cassandria, 2d, 3d, 6th, 7th, 8th, 9th, 26th; Johnstown, 1st, 3d, 6th, 7th, 9th, 11th, 12th, 15th, 16th; Emporium, 2d, 3d, 9th, 13th, 14th, 15th, 16th, 18th, 26th, 30th; Mauch Chunk, 3d, 7th, 16th, 23d; State College, 3d, 6th, 7th, 14th, 15th, 16th, 26th; Grampian, 2d, 3d, 15th; Lock Haven, 3d, 4th, 7th, 8th, 9th, 11th, 13th, 14th, 15th, 16th, 26th; Bloomsburg, 3d; Uniontown, 9th, 15th, 25th, 26th; Huntingdon, 3d, 4th, 15th, 16th, 26th; Kilmer, 3d, 16th, 17th; New Castle, 2d, 3d, 6th, 7th, 8th, 9th, 11th, 12th, 13th, 14th, 15th, 16th, 25th, 26th; Wilkes-Barre, 3d; Kane, 3d, 25th, 26th; Greenville, 13th, 14th, 15th, 25th, 26th; Easton, 7th, 23d; *Philadelphia* [Centennial Avenue], 3d; Shingle House, 16th, 26th, 27th, 30th; Somerset, 9th, 25th, 26th, 27th; Wellsboro, 2d, 3d, 6th, 7th, 8th, 9th, 10th, 11th, 12th, 13th, 14th, 15th, 16th; Dyberry, 2d, 3d, 4th, 5th, 6th, 7th, 8th, 9th, 10th, 11th, 12th, 14th, 15th, 16th, 25th, 26th, 30th; Honesdale, 24th; South Eaton, 2d, 3d, 6th, 7th, 8th, 10th, 11th, 12th, 15th, 16th; York, 3d, 6th, 7th, 9th.

Aurora.—Saegerstown, 15th.

Coronæ.—Philadelphia [Centennial Avenue], 16th; [Locust Street], 16th.

Solar Halo.—Philadelphia [Weather Bureau], 3d, 18th, 27th; [Centennial Avenue], 3d, 18th, 26th; Wellsboro, 27th.

Lunar Halo.—Phœnixville, 18th; Saegerstown, 15th; *Philadelphia* [Weather Bureau], 18th [Centennial Avenue], 18th.

JUNE WEATHER.

From United States Weather Bureau Records.

The following data, compiled from the records of observations taken during the length of time given at each station, show the average and extreme conditions during that time, and also the range within which weather variations may be expected to keep in any future June.

	Philadelphia. (23 years.)	Pittsburgh. (23 years.)	Erie. (21 years.)
Mean or normal,	72°	71°	67°
Warmest June, Average,	1802 74°	1892 75°	1876 71°
Coldest June, Average,	1881 67°	1878 66°	1881 62°
Highest temperature recorded, Date,	98° 20th, 1893	98° 28th, 1874	91° 28th, 1874; 24th, 1875
Lowest temperature recorded, Date,	47° 15th, 1884	39° 7th, 1879	42° 7th, 1879
Average date of last "killing" frost (spring),	April 9th	April 27th	April 30th
Average precipitation (inches),	3·20	3·63	4·08
Average number of days with ·01 inch or more,	10	12	12
Greatest monthly precipitation, Date,	6·81 1887	6·95 1881	6·84 1885
Least monthly precipitation, Date,	0·74 1885	1·47 1876	1·22 1891
Greatest amount in 24 hours, Date,	2·88 22d and 23d, 1887	2·52 9th, 1881	3·64 6th, 1887
Average number clear days, Partly cloudy, Cloudy,	9 13 8	8 15 7	9 13 8
Prevailing direction of wind,	SW	NW	S and SW
Highest velocity, miles per hour, Date,	46 1st, 1889	35 11th, 1890	35 10th, 1888; 7th, 1889; 4th, 1890